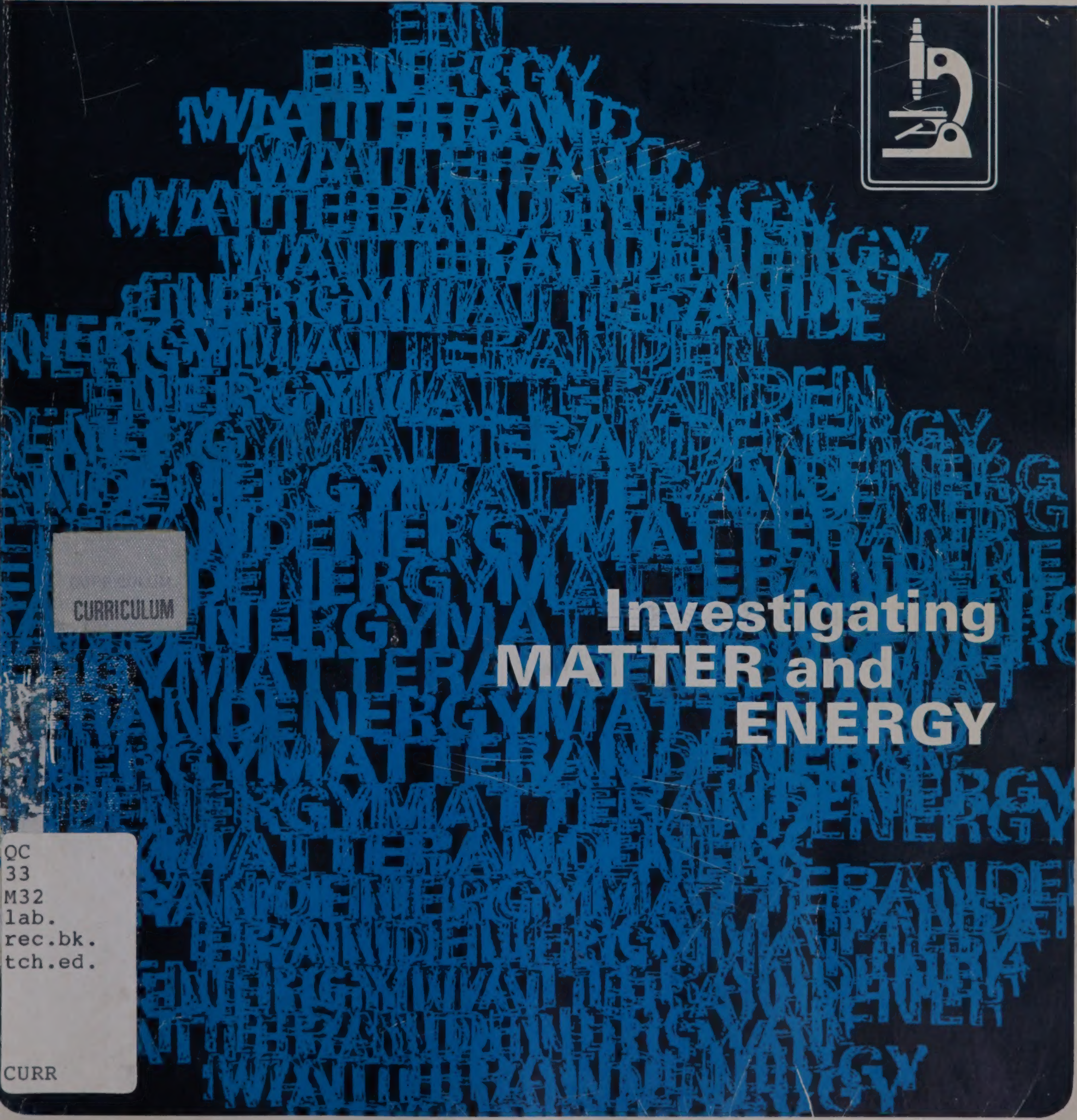
Teachers' Edition

Laboratory Record Book f

PHYSICAL SCIENCE

A LABORATORY APPROACH



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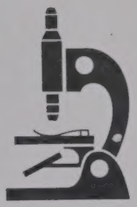

Teachers' Edition

Laboratory Record Book
for

PHYSICAL SCIENCE
A LABORATORY APPROACH

Investigating MATTER and ENERGY

John H. Marean · Elaine W. Ledbetter

ADDISON - WESLEY PUBLISHING COMPANY
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To the Teacher

This laboratory record book was designed as a compromise between the completely blank notebook and the highly structured workbook. Students need the guidance of examples and suggestions to lead their thinking. They are at an early stage in their experience with writing and reporting. As a counterbalance the students also need to have the freedom to organize their thoughts and to express them in brief sentences and paragraphs of their own design. We hope that this record book represents a desirable balance between guidance and freedom of expression.

The annotations in the experiments for Chapters 1 and 2 are addressed to you, as the teacher. They contain suggestions about how to lead students into the experiments and how to get them started in composing the reports. In succeeding chapters suggestions of this kind become unnecessary, so the annotations are statements and data that are more nearly what you might expect a student to produce.

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Guide to Using the Laboratory Record Book

The professional scientist organizes, records, and interprets all his experimental data. This Laboratory Record Book is designed to guide you in preparing a similar summary of your experiments. Each experiment begins with a problem — a question that arises from a puzzling aspect of our surroundings — and should end with an answer to that question.

We have listed seven elements that are basic steps in scientific experimentation and recording.

1. *Problem:* A problem is stated for each experiment. If the problem is difficult, it might be wise for you to restate it in your own words in the additional space that is provided.

2. *Hypotheses:* A hypothesis is a predicted answer to the problem under investigation. Every investigation in science must involve some guesswork regarding the solution to the problem. Your best guess should be the guide for investigation. We have provided a hypothesis for the problems through Experiment 2–2. Starting with Experiment 2–3 you will be expected to provide your own hypotheses. Always try to state more than one hypothesis even though you may be confident that one of them is a correct prediction.

3, 4. *Attack and Materials:* Local laboratory conditions and class discussion may lead to modification of the suggested attack and material used. Space is available under these entries for brief notes.

5. *Observations:* For experiments involving data collection, a table has been provided. If the data can best be organized by graphing, a grid has been provided. The length of the sides of the squares in the grid is one centimeter. If you need to subdivide them into tenths, it can be done quite easily with a metric ruler. The factor we change (the independent variable) is plotted horizontally, with numbers increasing to the right. The dependent variable, which changes as a result of variation in the horizontal values, is plotted vertically, with numbers increasing upward.

6. *Questions:* The questions will help you to formulate your concluding statements.

7. *Conclusions and Suggestions for Further Investigations:* Your statements must be connected to the problem and the hypotheses. Does the experiment answer the problem? Which hypothesis is verified? The suggestions for further investigation are an important part of experimental work. Most experiments raise new questions for each one that is answered. In addition, your ideas for further investigation provide an avenue of communication with your teacher, providing an exchange of ideas and allowing him to interpret your scientific thinking.

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Reporter ______________________ Date ______________

Team Members ______________________________

Problem: Is the growth of mold on bread influenced by the amount of moisture present?

Hypotheses: Yes, moisture will encourage the growth of mold on bread.

Alternate hypothesis: No, moisture will not encourage the growth of mold on bread.

Students should state their best guess as to what will happen and let their data provide an answer.

Attack:

1. Moisten one piece of bread; put it in a jar and seal the jar. Label the jar "moist sample"; include your last name and the date.
2. Put the piece of unmoistened bread in a second jar; seal and label the jar.
3. Place the jars side by side where they will be undisturbed.

Materials:

2 widemouth jars with tight-fitting lids
2 pieces of bread
2 labels

Observations: (Date each entry.)

Observations will vary somewhat, but after three or four days most of the moistened bread slices should show signs of mold. A few slices dry out and do not mold; a few do not mold even though they are moist. In rare cases, an unmoistened slice of bread develops mold. These variations provide opportunities for class discussion of controlled experimentation and can lead to more refined experiments.

Commercial bakeries often treat bread with a preservative (sodium propionate) which retards or prevents normal molding, even under the most favorable circumstances. Use a variety of breads, such as French, raisin, rye, and low-calorie. Include some with and some without preservatives.

Students will need help to distinguish between observations and interpretations. Stress that an observation is a direct statement of what happens, while an interpretation is an explanation of what happened. Interpretations should be included with their conclusions.

Questions:

1. What evidence have you observed that supports your hypotheses?

The moist bread probably molded in more cases than the unmoistened bread. Results will vary. This offers an opportunity to discuss the need for many repetitions of an experiment.

2. How do your results compare with those obtained by other members of the class? Try to explain any differences.

Have students identify possible variations from sample to sample. Ask: Was the bread in the control jar really dry? How much water was put in the experimental jar?

3. What is the purpose of using two jars and two slices of bread? Would it be better to use four jars and four slices of bread?

The control jar is needed for an actual comparison between a moist and dry piece of bread. The use of more than one set of jars would show whether results in just one pair was accidental or whether the results could be expected time after time that the experiment was performed.

4. What other factors might influence the growth of mold on bread?

This question might lead to a discussion of such possible factors as light, heat, kind of bread, type of jar lid, and how tightly the jars were sealed.

Conclusions and suggestions for further investigations:

Conclusions relate to the original hypothesis and the original problem. Most students will conclude that the presence of moisture does encourage the growth of mold on bread.

Suggestions for further investigation offer excellent clues to the individual's real understanding of the problem. Perceptive students will see many implications. Point out that during the course of any experiment, new ideas will become apparent, and that answering one question usually leads to other questions. Encourage students to look out for variations of the original hypothesis. By making students aware of the importance of proper controls, accurate observations, and the significance of unexpected results early in the course, you can help to make them more adept at suggesting further investigations.

Reporter ______________________ Date ____________________

Team Members ____

Problem: How many faces of a marked sugar cube contain a spot?

Hypotheses: It is possible to determine the number of marked faces on a sugar cube by using indirect methods and by comparing experimental results with probable results.

More precise hypotheses can be made. For example, if the cube has one marked face, it will show 1/6 of the time; two marked faces, 2/6, or 1/3, of the time; etc.

Attack: By shaking a tall container in which the sugar cube is placed, many observations of the faces are possible. Results after shaking each time can be recorded and the whole group of observations studied.

Materials:

sugar cube with an unknown number of spots
tall container, open at one end

Observations: Tally of trials

+ = SPOT SEEN
O = NO SPOT SEEN

Trial	Spots	Trial	Spots	Trial	Spots	Trial	Spots
1	+	26	O	51	+	76	O
2	O	27	O	52	+	77	+
3	O	28	O	53	O	78	+
4	+	29	O	54	O	79	O
5	O	30	O	55	+	80	O
6	O	31	O	56	+	81	+
7	O	32	O	57	+	82	O
8	+	33	+	58	O	83	+
9	+	34	+	59	+	84	O
10	O	35	O	60	O	85	O
11	O	36	O	61	+	86	O
12	O	37	+	62	+	87	O
13	+	38	O	63	O	88	+
14	+	39	+	64	O	89	O
15	O	40	+	65	+	90	O
16	+	41	O	66	O	91	O
17	O	42	O	67	O	92	O
18	+	43	+	68	O	93	+
19	O	44	O	69	O	94	+
20	+	45	+	70	O	95	O
21	O	46	+	71	+	96	O
22	+	47	O	72	O	97	O
23	O	48	O	73	O	98	O
24	O	49	O	74	O	99	O
25	O	50	+	75	+	100	+
Total spots	10	Total spots	9	Total spots	11	Total spots	8

a. Total number of spots observed	38
b. Total number of faces observed	100
c. Calculated spots per face (a ÷ b)	0.38
d. Calculated spots per cube (c × 6)	2.28
e. Probable spots per cube	2

Questions:

1. Analyze the results from the first, second, third, and fourth sets of 25 trials. How do they compare with the results from 100 trials?

Trials	1–25	26–50	51–75	76–100
a. Spots observed	10	9	11	8
b. Spots/face (a ÷ 25)	0.40	0.36	0.44	0.32
c. Spots/cube (b × 6)	2.4	2.2	2.6	1.9

The larger the sample of trials, the more confidence we can place in the average as representing the real value. (Discussion continued below.)

2. If a sugar cube has a spot on only one face, in how many trials out of 100 would you expect one spotted face to show? If it has a spot on three faces? If it has a spot on four faces?

1 spotted face: 1/6 × 100 = 17 times
3 spotted faces: 3/6 × 100 = 50 times
4 spotted faces: 4/6 × 100 = 67 times

These are probabilistic hypotheses of the if-then type. In other words, for the first example, if a cube has one spotted face, then you would predict that that face would show 17 out of 100 trials. (Discussion continued below.)

3. Combine your 100 trials with the results obtained by four other classmates who seemed to have a similar cube, so that you have 500 trials. What does this do to the value for spots per face and spots per cube?

If students use the space in the table sparingly, they can add the information from four other students to their own experiment. Be sure they combine data only for what appear to be cubes of similar marking.

The result should reduce the amount of deviation from the probabilistic hypothesis for a cube of the particular marking.

Conclusions and suggestions for further investigations:

The student should be able to offer a conclusion about the number of spots on his cube. He should have considerable confidence in his conclusion in spite of the indirect nature of data collection. As you discuss conclusions, emphasize that the experiment is an example of the collection of indirect evidence. See if they can cite other simple situations where they use indirect evidence (such as concluding that a bird is in a tree because its song can be heard).

Further investigation: Verify further that a greater number of trials reduces the deviation from a probabilistic hypothesis. You might ask what faith students would place in one trial, in five, in ten, and so on, up to 1000. Some students may anticipate the next experiment and suggest the problem of observing more than one marked cube in every trial.

Discussion for question 1, continued: *The averages of a few trials sometimes fall close to the real value, and in other cases are very different from it.*

Discussion for question 2, continued: *Experimental deviations from the predictions will be reduced by an increase in the number of trials. Note how 100 trials compares with 25 in question 1.*

Reporter ____________________ Date ____________________

Team Members ____________________

Problem: What can be learned about spots on the faces of a collection of sugar cubes that cannot be examined separately?

Hypotheses: It is possible to obtain an average for the number of marked and unmarked faces of the collection of cubes.

Students can make more specific probabilistic predictions. It might be well to ask for such hypotheses as a way to orient students to the experiment.

Attack: Same as Experiment 1–2: shake the sugar cubes in a tall container several times, making observations of the visible faces each time. Study the resulting data as a source of conclusions.

You may wish to have your students work with fewer cubes than 4 and gradually build up to 4, 5, and 6.

Materials:

- collection of 4, 5, or 6 sugar cubes having faces with an unknown number of spots
- tall container, open at one end

Observations: Tally of trials (FIVE CUBES WERE USED)

Trial	Number of spots	Trial	Number of spots	Trial	Number of spots	Trial	Number of spots
1	3	26	1	51	1	76	2
2	0	27	3	52	1	77	3
3	1	28	2	53	3	78	2
4	0	29	1	54	0	79	1
5	2	30	2	55	2	80	1
6	2	31	1	56	1	81	1
7	2	32	0	57	1	82	3
8	2	33	0	58	2	83	2
9	1	34	3	59	2	84	1
10	1	35	1	60	2	85	1
11	1	36	0	61	3	86	3
12	0	37	2	62	2	87	1
13	1	38	2	63	3	88	4
14	2	39	2	64	3	89	2
15	3	40	1	65	3	90	2
16	2	41	2	66	1	91	2
17	2	42	2	67	2	92	2
18	0	43	2	68	1	93	2
19	1	44	2	69	4	94	2
20	2	45	2	70	2	95	0
21	1	46	3	71	2	96	1
22	0	47	3	72	0	97	1
23	3	48	2	73	2	98	3
24	2	49	3	74	0	99	2
25	1	50	0	75	1	100	2
Total	35	Total	42	Total	44	Total	46

Six spotted faces observed ——— times

Five spotted faces observed 0 times

Four spotted faces observed 2 times

Three spotted faces observed 17 times

Two spotted faces observed 40 times

One spotted face observed 28 times

No spotted faces observed 13 times

a. Total number of spots observed = 167

b. Total number of faces observed = 500

c. Fraction of faces with spots (a ÷ b) = 0.334

$5 \times 0 = 0$

$4 \times 2 = 8$

$3 \times 17 = 51$

$2 \times 40 = 80$

$1 \times 28 = 28$

$0 \times 13 = \underline{0}$

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If this table is extended to include another column for spots, then it can be used to check the tally of total spots, as shown.

Questions:

1. What is the average number of spots per cube in your set of cubes? [(a ÷ b) × 6]

(167 ÷ 500) × 6 = 2.00

The average number of spots per cube need not be an integer when more than one cube is used. For example, with just two cubes, if one had one spot and the other two spots, the average number per cube would be 1.5.

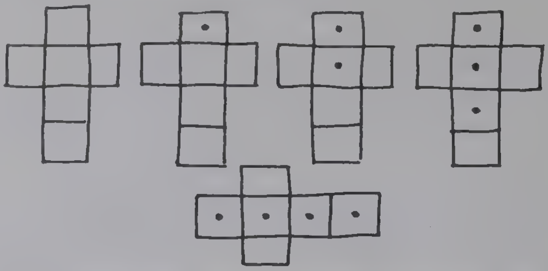
2. If your set of cubes had markings as follows, what would you predict, or hypothesize, as an average value for marked faces?

Cube 1 has two marked faces
Cube 2 has one marked face
Cube 3 has four marked faces
Cube 4 has five marked faces
Cube 5 has six marked faces
Cube 6 has no marked faces

Six cubes have a total of 36 faces. If 18 are marked, as above, then you would expect to infer from your experimental data that half the faces are marked (a ÷ b = 0.5).

3. What are some of the possible marking combinations that could produce the average you have obtained in this experiment?

See discussion below.



4. If you knew the actual markings on all but one of your cubes, could you use this information to determine the markings on this one cube? Explain.

Yes, the experimental data gives a way to compute total marked faces. Subtract number of known faces from computed total to get the value for the unknown cube.

Conclusions and suggestions for further investigations:

The answers to the questions show that much can be learned about a collection of cubes by indirect evidence and reasoning. The information has an increased element of uncertainty in it because of the number of cubes. It is important to stress that it is possible to learn something by performing this type of experiment. Watch for this realization as you examine student papers. This experiment also provides an opportunity to develop a sensitivity to the idea of probability.

Further investigations: (1) Make a systematic study of data produced by using cubes of known markings. (2) Study how the uncertainty changes as 2, 3, 4, 5, 6, etc., cubes are used.

Discussion for question 3: *The observations indicate that the fraction of faces with spots is 0.334, or 1/3. This means that out of a total of 30 faces on the five cubes, ten are spotted. There are many ways the ten spots can be distributed, but we are sure of two things: (1) No cube can have spots on all six faces. The observation of five cubes with blank faces on at least one trial indicates that each cube must have at least one blank face. (2) At least four cubes have at least one marked face, since four marked faces were seen at one time. That is, not more than one cube can be completely unmarked. But we cannot tell whether there is or is not an unmarked cube.*

Following are some possible distributions of the ten spots among the five cubes.

2, 2, 2, 2, 2
3, 2, 2, 2, 1
4, 2, 2, 2, 0
5, 2, 2, 1, 0
5, 3, 1, 1, 0
4, 3, 2, 1, 0

Possible distribution of marks on cubes can be shown by having students draw the unfolded sides of cubes, as illustrated above.

Reporter ______________________ Date ______________________

Team Members ____

Problem: How can items such as buttons be organized?

Hypotheses: Many objects, such as buttons, can be grouped according to their characteristics.

Buttons can be classed according to size, shape, color, number of holes, and kind of material.

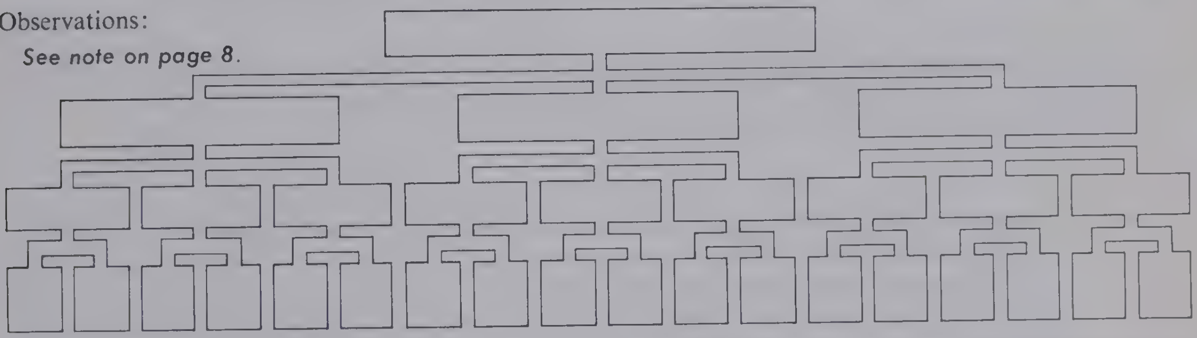
Attack: Study the buttons to establish a basis for categorizing them. Similarities in color, size, shape, and number of holes can be used as bases for categorizing.

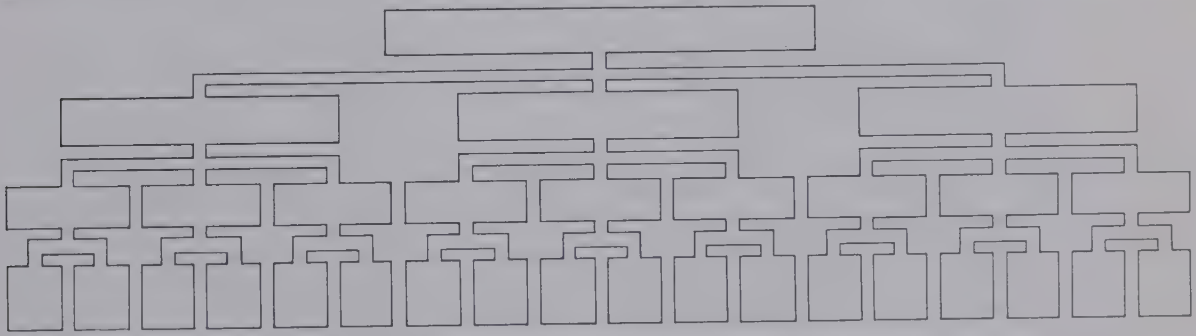
Materials:

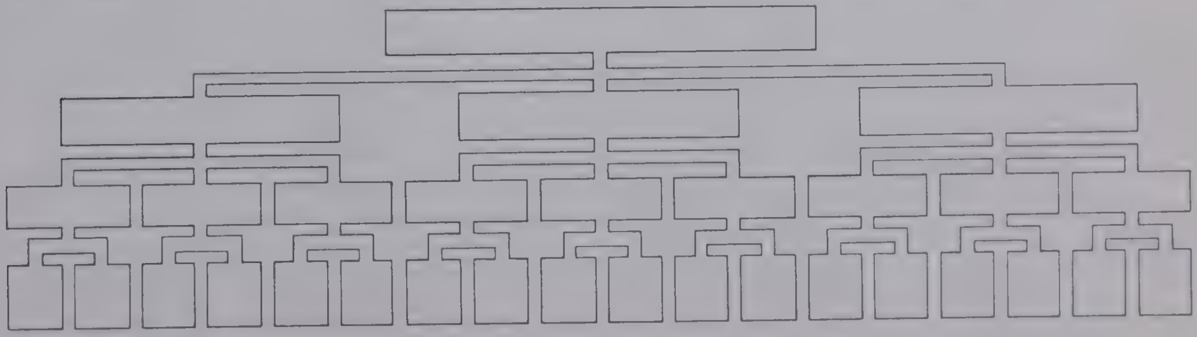
buttons, beads, washers, nuts, bolts, or other similar objects

Observations:

See note on page 8.







Questions:

1. How many classification systems have you devised for your collection?

Be sure the answers refer to a sequence of various attributes such as shape, color, and number of holes, not just to separate attributes.

2. What are some qualities that a good classification system should possess?

It must be a useful way to organize either actual objects or our knowledge of them. With knowledge, a good classification scheme helps to unify factual information.

3. What classification systems are used as part of the organization of your school?

A school is populated by faculty and students. The teachers are classed by the subject matter they teach. Students are classed by grade level for academic courses, by sex for physical education, and by interests because of their election of certain subjects and their involvement in extracurricular activities.

4. Natural objects, both living and nonliving, represent a great variety. What are some of the classification systems for these objects?

Living things are separated into animals, plants, and protists. Animals are further separated into vertebrates and invertebrates; vertebrates into mammals, birds, amphibians, etc. Nonliving materials are categorized as elements and compounds; or or solids, liquids, and gases; etc.

Conclusions and suggestions for further investigations:

If an appropriate collection of objects has been put together, students will experience some frustration as a consequence of their efforts to classify. Natural objects in particular do not fall neatly into categories, so the development of a scheme that interrelates all properties is difficult to accomplish.

Through discussion, help students to distinguish between merely identifying a category level and assembling several category levels together to form a scheme. The tendency will be to treat categories and classification schemes as synonymous. Watch for student sensitivity to this distinction as you examine their papers.

Further investigation: Anticipate the next experiment, which suggests using quantitative criteria for establishing categories. Watch for creative ideas from students about how to classify objects.

Note for observations on page 7: *Some students will settle for very crude categories; others will be too exacting. The question of whether one of a kind creates a category might arise. It would be best to set the rule that a category must have at least two items in it. The three trees are offered so that students can test several schemes or sequences of separation into categories. The illustration on page 13 of the text separates buttons into size, then number of holes, then light or dark in color.*

Reporter ______________________ Date ______________________

Team Members ____

Problem: How can measurements be used as a basis for classification?

Hypotheses: Measurements of objects can be used as a basis for grouping objects.

The hypotheses can be made precise by introducing the kind of measurement, such as diameter, length of a side if the button is square, and mass.

Attack: Measure the diameter or length of each object in a collection. Use the collection of measurements to identify categories based on size.

Determine the mass of each object and compare these values with the diameters as an alternative basis for categorizing.

Fit these size and mass measurements into a classification system that also uses other characteristics of the objects.

Materials:

- collection of buttons or similar objects
- metric ruler
- balance

Observations:

The process of measuring either diameter or mass becomes repetitive and educationally unprofitable rather quickly, so you might wish to have any one student do no more than ten measurements and then share information to increase the total sample of items.

Button	Diameter (mm)	Mass (g)	Button	Diameter (mm)	Mass (g)
1	28	2.35	21		
2	22	1.80	22		
3	28	1.60	23		
4	29	1.93	24		
5	27	1.00	25		
6	25	1.64	26		
7	27	1.63	27		
8	22	2.12	28		
9	28	1.12	29		
10	21	0.80	30		
11	22	2.60	31		
12	22	1.13	32		
13	18	0.60	33		
14	15	0.67	34		
15	17	0.80	35		
16			36		
17			37		
18			38		
19			35		
20			40		

Questions:

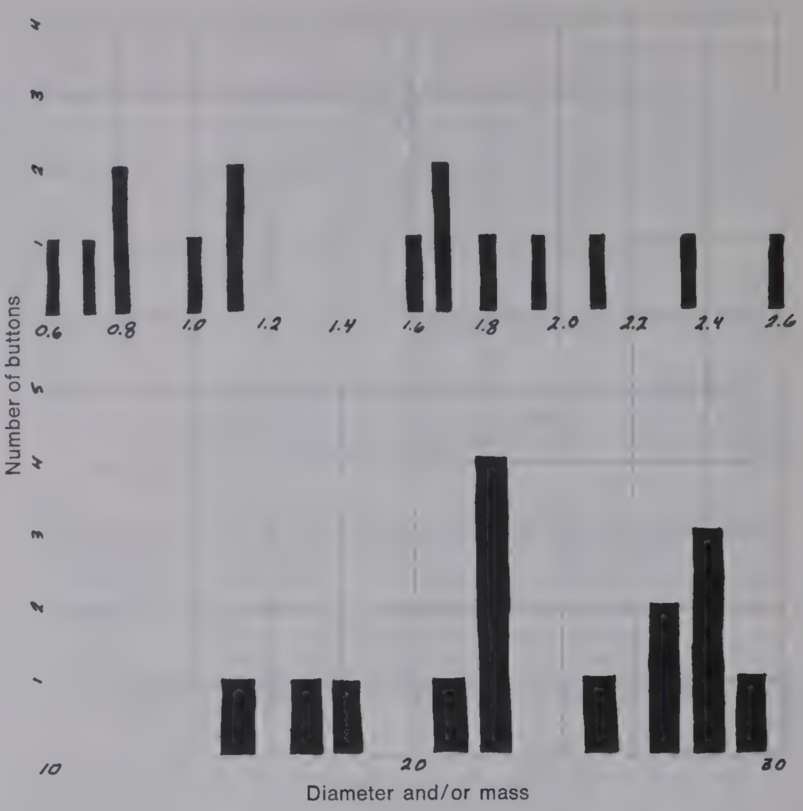
1. What are some advantages of a classification system based on measurements?

Measurement of size allows precise identification of items, the possibility of a great number of categories, and fine distinctions between categories.

2. Is it possible to use measurements as a form of classification without using categories? Explain your thinking.

Yes, it is possible because the unit of measurement is in itself a category. For example, since we have chosen to measure diameter in mm, 20 mm might be considered a category. Category divisions by size range are arbitrary and are set up for convenience.

3. Draw a histogram on the grid at the right. Plot the frequency (number of buttons) vertically for each size range listed along the horizontal axis.



4. What size button appears most frequently?

A diameter of 22 mm and a mass of 1.63, 1.64, and 1.60 g.

5. What is the median size?

22 mm, 1.6 g.

Conclusions and suggestions for further investigation:

For the sample of objects used, three size categories could be established: one could range from 14 mm to 19 mm, the second from 19 mm to 24 mm, and the third from 24 mm to 30 mm. Three mass categories could also be established: one would range from 0.6 g to 1.3 g, a second from 1.3 g to 2.0 g, and a third from 2.0 g to 2.7 g. Students should note any noncorrelation of mass and diameter. This is quite notable in the sample used for illustration.

Further investigation: Obtain volume values for the buttons, noting whether the buttons are made of the same or different substances. This activity would provide valuable groundwork for the study of density

Reporter ____________________ Date ____________________

Team Members ____

Problem: What evidence for its structure can be obtained by watching water as it freezes, boils, and condenses?

Hypotheses: Close observation of freezing, boiling, and condensing can provide insight into the structure of water.

Alternate hypotheses: (1) From observations of water as it freezes, boils, and condenses, we can conclude that matter is made of particles. (2) From observations of water as it freezes, boils, and condenses, we can conclude that matter is continuous. (Students are attempting to learn about the structure of matter and to determine which of the possible theories proposed is best.)

Attack: Boil a small amount of water in a test tube. Condense and freeze moisture on the surface of a can. Examine the moisture and the frost with a magnifier and, if possible, under the microscope.

Materials:

test tube
water
magnifier
glass slide
test tube holder
source of heat
small metal can
table salt
crushed ice
microscope (optional)

Observations:

Drops of water collect in the test tube near the mouth before water boils.
Steam seems to be continuous when it comes out in large amounts.
Steam changes to drops of water when it hits a cold can.
When steam touches the can, water forms in small puddles.
Crystals form around the edge of the puddles.
Crystals get bigger and finally form into ice.
Ice is a solid lump, but frost is more like snow.

Steam, water, frost, and ice all lead students toward the hypothesis that matter is continuous. Do not force the issue of the particular nature of matter. Ask leading questions to stimulate thinking and to make them critical of any conclusions. Try to get students to keep in mind that our ability to see particles may depend upon the degree of magnification. Many young people are adept at knowing what the teacher wants them to say—and they say it whether or not they themselves believe it. A primary aim of this course is to train youngsters to observe for themselves and to report honestly what they observe.

Questions:

1. Does water seem to leave the test tube in a continuous stream as it boils away, or does it seem to leave in particle form?

Most students see it as a continuous stream. Do not press the point at this time. Their honest opinion is important.

2. Does the water look continuous or particulate as it condenses on the cold can?

Many report that it forms in tiny puddles. To them the puddles seem to be continuous, though many such puddles may form on the can.

3. What evidence have you observed for continuous or particulate qualities in the frost on the can?

Frost forms in patterns which many students interpret to be particles. If it forms rapidly, it tends to appear continuous.

4. Can you build a mental picture of continuous matter going through the processes you have observed? Of particles going through the processes?

Students tend to answer yes or no without elaboration. Try to elicit a more detailed account of of how they visualize matter going through these processes as particles or as a continuous substance.

Conclusions and suggestions for further investigations:

Students will tend to draw conclusions that are not warranted by the experiment. Make comments that encourage them to confine and link their conclusions to those justified by actual observations. Students may produce defensible conclusions for both theories. Compliment them for the quality of their conclusions. In fact, conscientiously avoid the idea that any theory is correct.

The appearance of the water as liquid and as ice does seem to favor the continuous theory, but does it exclude the particle idea? Also, what is continuous about the vapor form of water? Can its existence as a vapor be explained by either theory? Help students develop chains of logic associated with these questions.

Further investigation: Explore whether other substances behave in the same way. What implications does the existence of many kinds of substances have for the two theories? Can either one explain the great diversity of matter better than the other? Point out that investigation can be mental only; it does no have to involve an experiment.

Reporter ______________________ Date ______________

Team Members ______________________________

Problem: What evidence for sulfur's structure can be obtained by observing sulfur before it melts, as it melts, and as it cools?

Hypotheses:

(1) Sulfur is composed of particles.
(2) Sulfur is continuous matter.
(3) Sulfur has both particulate and continuous structure.

Attack: Examine sulfur with a magnifier and, if possible, with a microscope. Melt the sulfur by heating it and solidify it by cooling in the air and then pouring into some water. Then dissolve some of it in carbon disulfide.

Materials:

- piece of roll sulfur
- small test tube
- test tube holder
- source of heat
- glass slide
- filter paper
- funnel
- stirring rod
- magnifier
- beaker
- cold water
- carbon disulfide
- microscope (optional)

Observations:

(1) Sulfur is a hard, yellow solid. It appears to be grainy.
(2) Sulfur is hard and solid, but breaks easily into tiny pieces when tapped with a knife.
(3) When heated, the sulfur became a yellow liquid at first, then it turned orange. As heating continued it became black and almost like gum. Then it became watery again but not as much as before.
(4) When the black watery sulfur was poured into water, it formed long black strings that acted like rubber. They would stretch and could be rolled into balls. Some pieces of yellow sulfur floated on the water and acted like mercury.
(5) When sulfur was heated to the yellow watery stage and poured into the filter paper, it very quickly became a yellow solid again.
(6) When the paper was pulled away from the sulfur, the sides were hard and smooth.
(7) In the middle of the cone the sulfur had formed many needle-like points in all directions. These crystals were about ten times as long as wide. They were thin and wedge-shaped. They had a smooth, glossy surface.
(8) When sulfur dissolved in carbon disulfide and the liquid evaporated, the sulfur was solid again and formed diamond-shaped crystals. The color did not change.

As a supplement to this experiment, you might dissolve sulfur in toluene and let crystals form from it as they did from carbon disulfide.

Questions:

1. Did you detect any evidence that some of the sulfur had vaporized?

Yes, yellow powder formed in the neck of the test tube. This was similar to the water drops that formed when steam was made from water.

2. Suggest reasons why sulfur changes its color and its liquid character as you continue to heat it. Try to use both a particle theory and a continuous theory for your reasons.

If the particle theory is assumed, students may say that heating caused the pieces to move apart enough to flow. Color change is not easy to explain, but some students will have ideas that show thought. The actual explanation is that the crystal first breaks into large molecules, each containing eight sulfur atoms. Further heating breaks the molecules open so they can form chains by one set of eight atoms joining another.

3. How are sulfur crystals similar to and different from water crystals?

Sulfur crystals, like water crystals, are hard and have a definite shape, but their shape is different from water crystals.

4. How does the amorphous sulfur change a few days after its manufacture?

It becomes hard and loses its rubbery characteristics. After a long time, yellow crystals may become apparent.

Conclusions and suggestions for further investigations:

These data tend to indicate the validity of the particle theory: (1) The hard sulfur breaks into tiny pieces, (2) The hard sulfur melts and flows, (3) The sulfur dissolves in carbon disulfide, and after the liquid has evaporated, small diamond-shaped crystals again appear.

The amorphous sulfur is more consistent with the continuous theory because of its shapelessness and stretchiness. Again, the important point is to train students to observe, to think, and to draw logical conclusions which are actually based upon their observations. If you encourage the particle theory, they will sense that this is the "right" one and will respond accordingly. Leave the question open, but through class discussion of the pros and cons and further experimentation, the evidence will gradually become convincing that matter is particulate in structure.

Further investigations: (1) Heat the needle-like crystals to see if they behave like the original hard sulfur. (2) Heat the rubbery sulfur to see if it returns to the hard, yellow state. (3) Pour the yellow liquid sulfur into cold water to see what happens. (4) Heat the diamond-shaped crystals to see if they behave like the original sulfur.

Reporter ______________________ Date ______________

Team Members ______________________________________

Problem: Can a large marble model be built that would have the regular appearance exhibited by crystals?

Hypotheses:

If crystals are made of tiny particles, then a model built of visible pieces should have a regular shape that would resemble a real crystal.

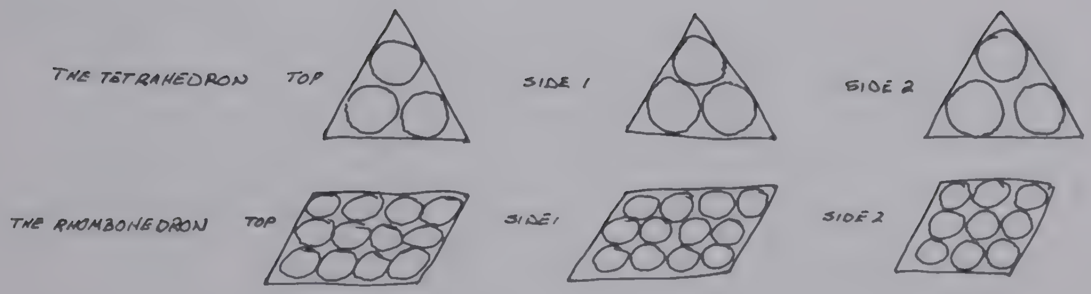
Attack: Use marbles to build models that show the same regular angles and sides exhibited by crystals.

Materials:

50 to 75 marbles or other spheres
quick drying cement
candle
several strips of cardboard

Observations:

In this experiment students might trap themselves into giving a description of the procedure they used to build the models. This approach is not entirely incorrect, but it can miss the point. Ask students what kind of observations they should record, and in this way help them realize that the important observation is that the models have regular shapes. Bring this out by having the students make simple sketches of the models from the top and two sides. Examples appear below.



Questions:

1. Do your models show evidence of faces with fixed angles between them similar to those observed in crystals?

Yes, they do; the sketches show that the various faces can be enclosed in geometric figures.

2. What would happen if some of the marbles were of a different size?

The shape of the model would not be regular. It would not fit together very well.

3. Do the particles for models necessarily have to be spheres? Could models be made with sugar cubes?

Models can be made with cubes; the cubes can be arranged to fit into any regular shape that a sphere fits in.

4. Do your models support the particle theory or the continuous theory?

The particle theory is favored because the models made with marbles resemble the shapes of real crystals we have studied.

Conclusions and suggestions for further investigations:

Since models of crystals can be built from marbles and cubes which resemble real crystals, the particle theory for the structure of matter is supported. It is difficult, if not impossible, to explain crystals with the continuous theory.

Further investigation: Attempt to make models of other kinds of real crystals.

Reporter ______________________ Date ______________________

Team Members ____

Problem: Do the forms of sulfur differ in density?

Hypotheses:

(1) If sulfur is made of particles, the differences between various forms of sulfur are due to variation in particle arrangement.

(2) If differences in the density of the forms of sulfur exist, they may be interpreted as evidence for differences in the packing of particles.

Attack: Determine the density of the various forms of sulfur by obtaining volume and mass for each form and then compare the values.

Materials:

- roll sulfur
- amorphous sulfur
- 100-ml graduated cylinder
- balance

Observations:

Expect a wide spread of results, due especially to poor volume determinations. Below is one tally of class results for fresh and day-old values of amorphous sulfur by this method. Suggest that students pool data and construct a histogram. Then determine an average. In the class data shown, the old amorphous sulfur is slightly denser. Actually it is, but the values should be between 1.90 and 1.95 g/ml.

DENSITY	NO. OF STUDENTS WHO FOUND THIS VALUE	
	FRESH	DAY-OLD
1.0 g/ml	1	
1.1	3	
1.2	3	2
1.3	2	3
1.4	2	3
1.5	2	4
1.6	2	1
1.7	8	5
1.8	2	1
1.9		1
2.0	1	1
2.1		
2.2	1	
CLASS AVG.	1.52 g/ml	1.54 g/ml

Kind of data	Trials with roll or crystalline sulfur						Trials with amorphous sulfur				
	1	2	3	4	5	6	1	2	3	4	5
a. Mass (by weighing) (g)	2.0						3.0	5.3			
b. Initial volume of water (ml)	50						50	50			
c. Volume of water plus sulfur (ml)	52						53	54			
d. Volume of sulfur (c − b) (ml)	2						3	4			
e. Density of sulfur (a ÷ d) (g/ml)	1.0						1.0	1.3			

Questions:

1. Do your results indicate a density difference in the forms of sulfur?

Not consistently.

2. Do your results indicate that the density of each kind of sulfur is constant?

Probably not.

3. What kinds of errors might have caused your trials on the same sample to vary?

The method of determining volume is not precise. Also, amorphous samples may contain water, which would alter their density determination.

4. If this experiment produced evidence that the samples were the same in density, would you accept this as a valid result? Explain.

The inability to obtain precise values for the volumes should make any result questionable for this experiment.

5. How do the results of this experiment fit into the two theories of matter?

The experiment should be viewed as producing inconclusive results which do not allow formulation of an answer for this question.

Conclusions and suggestions for further investigations:

This experiment does not produce data that forms a basis for an answer to the original question. A better way to determine volume or another way to determine the density must be found. This is a valuable experiment because it does show that experiments can be failures.

Further investigation: Gather suggestions from students for getting reliable data in this experiment. (A more reliable method of determining the densities of various forms of sulfur is given in Experiment 2–8.)

Reporter ______________________ Date ______________________

Team Members ____

Problem: What is the relation of the mass of a floating object to the mass of the liquid it displaces?

Hypotheses:

The mass of a floating object will either be equal to, less than, or greater than the mass of the liquid it displaces.

Attack: Compare the mass of the floating object with the mass of the liquid that was displaced as the object sank into the liquid.

Materials:

wooden sample, 5 to 10 cm long cut from 2-cm doweling
100-ml graduated cylinder
balance
water
gasoline, kerosene, or alcohol

Observations:

Observations:	Samples			
Kind of data	1	2	3	4
a. Initial volume of water	50 ml	50 ml	50 ml	
b. Final volume (water plus sample)	70 ml	64 ml	67 ml	
c. Volume of submerged portion of sample (b − a)	20 ml	14 ml	17 ml	
d. Initial mass of water plus graduated cylinder	181.0 g	181.0 g	181.0 g	
e. Final mass of water, container, and sample	201.7 g	195.3 g	198.2 g	
f. Mass of sample (e − d)	20.7 g	14.3 g	17.2 g	
g. Density of water (f ÷ c)	1.0 g/ml	1.0 g/ml	1.0 g/ml	
h. Mass of container filled with water to level recorded in (b)	201.7 g	195.3 g	198.2 g	
i. Mass of water displaced (h − d)	20.7 g	14.3 g	17.2 g	
j. Density of water added (i ÷ c)	1.7 g/ml	1.0 g/ml	1.0 g/ml	
l. Initial volume of gasoline	59 ml	57 ml	55 ml	
m. Final volume gasoline + sample	88 ml	76 ml	81 ml	
n. Volume of submerged portion of sample (m − l)	29 ml	19 ml	26 ml	
o. Initial mass of gasoline + container	171.2 g	169.7 g	168.1 g	
p. Final mass of gasoline, container, and sample	191.9 g	184.0 g	185.3 g	
q. Mass of sample (f)	20.7 g	14.3 g	17.2 g	
r. Density of gasoline (q ÷ n)	0.71 g/ml	0.75 g/ml	0.66 g/ml	
s. Specific gravity of gasoline $\frac{r}{g}$ or $\frac{r}{j}$ or $\frac{c}{n}$	0.71	0.75	0.66	

Questions:

1. What can you say about the density of an object that sinks in water?

This experiment shows that floating objects are less dense than water. From this, one might project that objects that sink are heavier than water.

2. What does this experiment imply about the density of ice as compared to the density of water?

Since ice floats we can conclude that it is less dense than water.

3. Density is a constant property for each substance that we know. Offer some possible explanations for this statement, using a theory for the structure of matter.

Constant density may mean that the particles that comprise a substance are constant in mass and in the way they are arranged in crystals of the solid.

4. Why does the wooden cylinder displace more gasoline than water?

The experiment suggests that the mass of the floating object is equal to the mass of the liquid displaced. The gasoline is less dense than water, so the same object has to displace more gasoline by volume to displace an equal mass of gasoline.

Conclusions and suggestions for further investigations:

A floating object displaces a mass of liquid equal to the mass of the object. This is the primary conclusion of this experiment. Students might tend to extrapolate by saying that an object that is the same density as water will barely float. If it is more dense than water, then it cannot displace water equal to its mass and thus cannot float. If students make statements like this one, point out that they are excellent hypotheses, but that they need testing.

Further investigation: Challenge students to design an experiment that checks the hypothesis stated above. A Cartesian diver made from an inverted test tube in a bottle of water is a qualitative way to extend this experiment.

Reporter ______________________ Date ______________________

Team Members ______________________

Problem: To build a hydrometer. A hydrometer is better suited to measuring the specific gravity of liquids than a wooden cylinder.

Hypotheses:

The cylinder tends to tip over. If one end can be heavily weighted, then it will stand up straight in the center of a tube or graduate.

Attack: For Experiment 2–6 the transparent plastic drinking straw serves as the floating object. Seal one end with a small bolt that will concentrate the mass at one end. Then insert a narrow, numbered piece of paper into the straw as a scale.

For Experiment 2–7 float the hydrometer in water and then in gasoline. Use the table below to record depths and specific gravities.

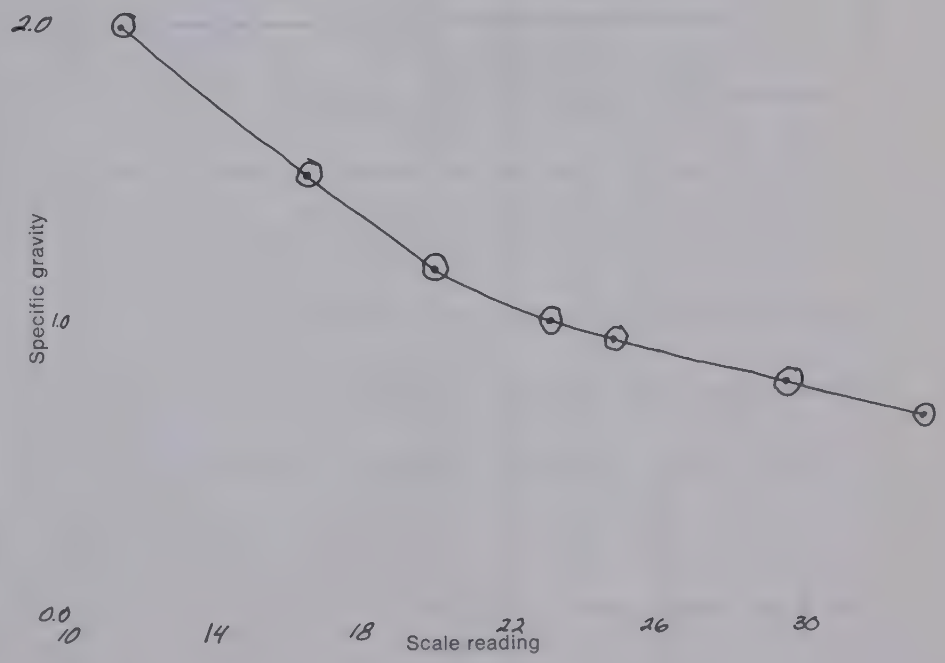
Materials:

transparent plastic drinking straw
household cement
lined paper
bolt
scissors
tall cylinder
gasoline
tall container

Observations for Experiment 2–7:

a. Total length of hydrometer	34.0	divisions
b. Depth reading in water	23.2	divisions
c. Depth reading in gasoline	29.5	divisions
Specific gravity of gasoline $\frac{b}{c}$ =	0.79	

Scale reading	Depth reading in water divided by each scale reading	= Specific gravity
23.2	1.00	1.0
11.6	2.00	2.0
15.5	1.50	1.5
20.0	1.16	1.16
25.0	0.93	.93
29.5	0.79	.79
33.0	0.70	.70



Questions:

1. Why is your hydrometer a better instrument for measuring specific gravity of liquids than the wooden cylinder?

It is longer and has built-in graduations that allow quick readings to be taken.

2. By reading your graph determine the specific gravity of your hydrometer.

The total length of the hydrometer used by the author was 34.0 units. In a liquid with the same specific gravity as the hydrometer itself, the depth reading would be 34.0. Such a liquid has a specific gravity of 0.68, according to the graph.

3. Why is your study of density important to the overall study of the structure of matter?

Density is a property of matter. It has a unique value in each substance. If this can be explained more satisfatcorily by one theory or another, then we have another basis for choice of theory.

4. Explain how density could be useful as a basis for classifying matter.

Density is measurable; it can be one property to use as a basis for a set of categories, or it can be used as a continuum with distinctions being indicated by numerical values.

Conclusions and suggestions for further investigations:

A long, slender, lightweight tube with most of its weight in one end can be equipped with a scale and a supplemental graph. It then is a handy instrument for determining the specific gravity of liquids in which it will float.

Gasoline is found to be less dense than water, and thus the hydrometer has to sink into it deeper to displace its own weight and the weight of the liquid.

Further investigations: (1) Determine specific gravities of many liquids, including solutions of varying strength. (2) Find the maximum and minimum specific gravities that the student hydrometer will measure.

Reporter ______________________ Date ______________ 2 8 page 48

Team Members ______________________________________

Problem: Can the density of a liquid mixture be adjusted to make it possible to detect very small density differences in samples of solids?

Hypotheses:

If two mixable liquids differ greatly in density, then mixtures of varying density can be prepared. A mixture can be adjusted to cause an object to float or sink and very fine distinctions in density can be made.

Attack: Tetrabromoethane has a density of 2.96 g/ml. It mixes readily with butyl carbitol (density 0.95 g/ml). Float the sulfur samples on a small quantity of tetrabromoethane. Then add butyl carbitol, drop by drop, until the sulfur sinks. Use your hydrometer to determine the specific gravity value of the mixture.

Materials:

- tetrabromoethane
- butyl carbitol
- samples of roll sulfur, rhombic sulfur, monoclinic sulfur, and fresh and old samples of amorphous sulfur
- test tube
- hydrometer
- dropper

Observations:

Hydrometer reading	Observation
1.97–2.07 g/ml	*Roll and rhombic sulfur sink, while monoclinic and fresh amorphous remain afloat. The old amorphous may sink, depending on its age.*
1.92–1.97 g/ml	*Monoclinic sulfur sinks. Old amorphous sinks if it did not when the solution was denser.*
less than 1.92 g/ml	*Fresh amorphous sinks.*

Questions:

1. What does this experiment show about the densities of the various kinds of sulfur?

Fresh amorphous sulfur is the least dense. Both old amorphous and monoclinic sulfur are denser than fresh amorphous but less dense than roll and rhombic.

2. Does this method provide a more precise way of detecting density differences than Experiment 2–4? Explain.

Yes, floating or sinking in the mixture of liquids used provides a very sensitive indicator of differences in density.

3. How can the precision of experiments affect the opportunity to draw conclusions?

In this case, a conclusion is possible. In Experiment 2–4 lack of precision made conclusions about density impossible.

4. Devise explanations for the difference in density of the same substance by using the two theories for matter.

In its three forms sulfur is still the same substance but has a reorganized form. The theory that can explain the three forms is the more desirable one. The particle theory suggests reorganization of particles; the continuous theory does not.

Conclusions and suggestions for further investigations:

Liquid mixtures can be adjusted very delicately so that small differences in density of floating objects can be detected. This technique can be used to show that the three forms of sulfur are slightly different in density.

Further investigation: Study other materials which vary only slightly in density.

Reporter ______________________ Date ______________

Team Members ______________________________

Problem: What are the characteristics of solutions?

Or, what can we learn about the structure of matter from a study of solutions?

Hypotheses:

Through discussion, help students generate hypotheses about how continuous matter would dissolve and how particles would dissolve. Following are examples.
(1) In a solution continuous matter of one kind will spread uniformly through another sample of matter if the two interpenetrate.
(2) In a solution individual particles of one kind of matter will be separated by particles of the other kind.

Attack: Select a number of common laboratory substances and attempt to dissolve them in water. Examine a drop of each solution under a microscope and then evaporate the drop. Filter each solution and examine the filter paper for a residue. Taste the salt and sugar solutions.

CAUTION: Do not taste the copper sulfate—it is poisonous.

Materials:

sugar cubes
rock salt crystals
copper sulfate crystals
filter paper
funnel
glass slides
stirring rod
150 ml beaker
6 20-by-150-mm test tubes
test tube rack
microscope
heat source
water

Observations:

	Sugar	Salt	Copper sulfate
Taste	SWEET	SALTY	
Color	COLORLESS	COLORLESS	BLUE
Appearance of particles	CANNOT SEE	CANNOT SEE	CANNOT SEE
Is the solid recovered by heating?	YES	YES	YES
Is the solute removed by filtering? *	NO	NO	NO

SUGAR CRYSTALS HAVE A CUBICAL SHAPE.

COULD SEE NOTHING IN A DROP OF SOLUTION UNDER THE MICROSCOPE EXCEPT UNIFORM, VERY LIGHT COLOR OF THE COPPER SULFATE SOLUTION.

(Include sketches of crystal form as part of your record of observations.)

** If students put more sugar, salt, or copper sulfate in water than can dissolve, they will be able to remove this by filtering, so be sure they use amounts of solute that will dissolve completely.*

Questions:

1. What properties of solutions can you identify as a result of this experiment?

(1) Solutions observed are transparent, though they can be colored.
(2) Water can be removed by evaporation to recover solute.
(3) Solutes cannot be removed by filtering.

2. Can you see any reason why the same mass of crystals would dissolve more rapidly when crushed than as large pieces?

Yes, because more solute surface is exposed to the solvent (water) after crushing. This gives the solvent a better opportunity to contact the solid pieces.

3. If matter is made of particles, what does this experiment suggest about the size of the particles?

They must be very small since they go through filter paper which does not contain visible holes.

4. If given two test tubes, one containing water and one containing sugar solution, how could you identify the sugar solution?

Evaporate a drop from each test tube on a glass slide. The drop leaving a residue could be identified as the sugar solution.

(Note: Do not accept the taste test. Because many chemicals are poisonous, it is not a safe test to use in the laboratory.)

Conclusions and suggestions for further investigations:

Both the ability of solutions to pass through invisible holes in the filter paper and an observation of a drop of solution indicate that particles are very small. The spread of color in the copper sulfate solution suggests that the solution is continuous in nature. For two of the three solutions, the colorless, transparent condition makes the solutes disappear from view.

The general nature of solvents and solutions will tend to cause students to favor the continuous theory. This is a legitimate view, and yet it does not adequately explain the interpenetration. How does continuous matter penetrate other continuous matter? The particle theory can explain interpenetration by an intermingling of particles.

Further investigations: (1) Is the solute uniformly distributed in the solvent? (2) How much solute will dissolve in a specified amount of solvent? (3) Are all solutions like those studied in this experiment?

Reporter ______________________ Date ______________

Team Members ______________________________

Problem: Are solutions the only form of association produced when substances are mixed?

An alternate question: Do all mixtures of solids and water have the same properties as solutions?

Hypotheses:

When water and solids are mixed, the particles do not disappear as completely as they do when a solution forms.

Attack: Study a broader, more diverse sampling of substances than you did in Experiment 3–1. Filter each mixture of substance and water. Let the mixtures stand to see if the materials stay suspended or whether they settle out; shine a beam of light through each mixture. Classify them according to results.

Materials:

- 4 20-by-150-mm test tubes
- table salt
- liquid laundry starch
- finely crushed soil
- graduated cylinder
- stirring rod
- labels
- spoon
- funnel
- filter paper
- test tube rack
- light-beam source
- sugar cubes
- water

Observations:

	Sugar in water	Salt in water	Starch in water	Soil in water
Is the solid removed by filtering?	NO	NO	SOME	YES
Does the solid settle out?	NO	NO	SOME	YES
Does the mixture transmit light?	YES	YES	SOME	NO
Does the beam show in the mixtures?	NO	NO	YES	SOME, DEPENDING UPON DEGREE OF SETTLING.
Probable classification	SOLUTION	SOLUTION	DISPERSION	SUSPENSION

Questions:

1. What seems to be the fundamental difference between solutions, dispersions, and suspensions?

The size of the bits of material seems to be the fundamental difference. Any particles in solutions are invisible; dispersion particles can be seen under a microscope, and suspension particles can be seen with the naked eye.

2. Try to explain why light is affected as it is by the various mixtures.

If the particles are extremely small, as in solutions, they do not reflect light. As the particles become larger, they reflect some of the light, and as they become still larger, more light is absorbed than is reflected.

3. List some natural examples of solutions, dispersions, and suspensions.

Natural	Man-made
(a) sea water	*(d) gelatin*
(b) fog	*(e) mayonnaise*
(c) muddy water	*(f) whipped cream*

4. Use the particle theory and the continuous theory to explain the conditions represented by solutions, suspensions, and dispersions.

The continuous theory does not suggest explanations. By contrast, the particle theory provides a basis for the explanation given in question 2.

Conclusions and suggestions for further investigations:

Mixing water with solid substances does not produce a solution in all cases. Mixtures that can be classed as dispersions and suspensions occur as well as solutions. The differences can be explained by particle size. The continuous theory does not provide an explanation.

The very tiny particles assumed to exist in solutions remain uniformly scattered once they are dissolved. To a lesser degree, particles in dispersions also remain scattered. In suspensions, there is a distinct tendency for the particles to respond to gravity and to settle out.

Further investigations: (1) What will keep the large particles suspended? (One way is by shaking, because shaking keeps the particles moving fast enough to prevent settling. (2) What goes on in a solution to keep articles from settling? (Particles of solute are in constant motion.)

These questions anticipate the study of Brownian motion in Chapters 6 and 7.

Reporter ______________________ Date ____________________

Team Members ______________________________________

Problem: Does the specific gravity of a solution change with the amount of dissolved solute?

Hypotheses:

As more and more solute is added, the specific gravity of the solution will increase.

Attack: Use the hydrometer made in Experiment 2–6 and the graph made in Experiment 2–7 to determine the specific gravities for a series of sugar solution concentrations. Start with one cube dissolved and read the specific gravity, then add a second cube and read the specific gravity, etc.

Materials:

100-ml graduated cylinder (or tall test tube)
stirring rod
drinking-straw hydrometer
several sugar cubes
specific gravity graph from Experiment 2–7
water
balance (optional)

Observations:

Number of cubes dissolved	1	2	3	4	5	6	7	8	9	10
Hydrometer reading	15.9	15.8	15.7	15.5	15.3	15.2	15.1	15.0		
Specific gravity of solution	1.00	1.01	1.02	1.03	1.04	1.05	1.06	1.07		
Mass of sugar	2.12g	4.24g	6.36g	8.48g	10.60g	12.72g	14.84g	16.96g		
Mass of solution	82.1g	84.2g	86.4g	88.5g	90.6g	92.7g	94.8g	98.0g		
Mass of solvent	80g	80g	80g	80g	80g	80g	80g	80g		

(These were done by dissolving the cubes inside the 100-ml cylinder. However, if the experiment is done within a test tube, using a smaller amount of solvent, then the density changes are more marked and are easier to distinguish on the hydrometer. Note that the hydrometer here is not the one that gave the data for Experiment 2–7.)

Volume of water used 80 ml

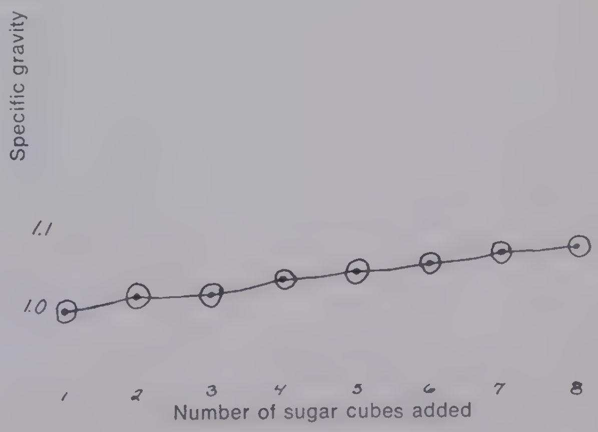
Mass of water used 80 g

Ask the students to measure the volume of the final solution. They need this to answer questions 2 and 3.

Volume of final solution = 88 ml.

One can check the accuracy of the hydrometer by comparing its reading with the calculated specific gravity of the sugar solution:

$$\text{density} = \frac{\text{mass}}{\text{volume}} = \frac{98.0\ \text{g}}{88\ \text{ml}} = 1.11\ \text{g/ml}.$$



Thus, the specific gravity from the hydrometer reading (1.07) appears to be slightly low.

Questions:

1. The density of sugar is 1.59 g ml. What do you find to be the average density of sugar cubes? Explain any difference between your answer and the value above.

The average mass of a sugar cube is 2.12 g for the 210 cubes/lb variety and the volume is about 2.2 ml. Their density, therefore, is about 0.92 g/ml. Air space in the cube causes the difference.

2. If 1.59 g of sugar are put into 10.0 ml of water, will the volume increase to 11.0 ml? Explain.

No, not according to the data of this sample. When 17.0 g sugar was added to 80 ml water, the volume increased by 8 ml. The volume of the sugar itself was

$$\text{volume} = \frac{\text{mass}}{\text{density}} = \frac{17.0\ \text{g}}{1.59\ \text{g/ml}} = 10.7\ \text{ml.}$$

Thus, volume of solution is less than volume of sugar plus volume of water.

3. What increase in volume does each sugar cube produce in your solution?

The increase in volume is about 1 ml for each cube in this sample.

4. Which theory for matter provides the best explanation for the observations made in this experiment?

If particles are assumed, we can visualize two kinds as fitting closer together than a single kind because of differences in size or shape.

The continuous theory simply allows us to say substances interpenetrate as liquids, but does not provide us a way to visualize how they intermingle.

Conclusions and suggestions for further investigations:

As more and more solute is dissolved in a given amount of solvent, the specific gravity gradually increases. The extent to which it increases varies with the solute used.

Further investigations: (1) What volume changes accompany dissolving a gas in a liquid? (2) Will other solids which dissolve in water add their exact volume to the solution?

Reporter ______________________ Date ______________ 3 4 page 60

Team Members ______________________________________

Problem: What happens to a hypo solution as it cools?

Hypotheses:

Either it will remain liquid, or some of the hypo will separate from the solution as a solid.

Attack: Dissolve a relatively large amount of hypo in water by heating very gently. Once all the hypo is dissolved, allow the solution to cool without disturbing it. When it is at room temperature drop a crystal of hypo into it. Observe the solution closely for appearance of crystals and any temperature change.

Materials:

distilled water
15 g of hypo
20-by-150-mm test tube
test tube rack

stirring rod
100-ml graduated cylinder
250-ml beaker
test tube holder
heat source

Observations:

(1) A very large amount of hypo can be dissolved in just a few milliliters of hot water.
(2) As the hot solution cooled, no crystals formed.
(3) A small crystal dropped into the cooled solution caused other crystals to form until a large part of what had been solution became crystals.
(4) As the crystals formed, the tube became quite warm.

Questions:

1. Does this experiment result in what might logically be expected?

Results will surprise most students because the hypo does not gradually settle out.

2. Suggest reasons why the hypo crystallized.

Heat was used to make the solution. It may be the way the heat is held that causes this manner of crystallization. Also, it seems that more water is present than the 2 ml that was used originally. If so, where does it go when the hypo crystallizes?

3. How can you explain the great increase in solubility of hypo as the temperature went up?

Apparently water is released as the crystals melt, providing more water in which still more crystals can melt.

4. What does this experiment contribute to your efforts in judging the validity of the two theories for matter?

The liquid condition can be viewed as one form of particle association, and the solid condition as a second form. Something must initiate the change from the liquid to solid form. Continuous matter, it seems, would not display such a sharp, sudden tendency to change.

Conclusions and suggestions for further investigations:

This experiment will generate interest and a desire to do further experimentation more than it will generate any firm conclusions. One conclusion is that hypo shows unusual behavior. In addition, enough students may have encountered trouble in getting a supersaturated solution that they will conclude that the experiment must be done very carefully.

Further investigations: (1) Do other solutes produce supersaturated solutions? (2) Does a sample of supersaturated hypo crystallize if some other substance is dropped into it? (3) What happens if crystals of hypo are heated? (4) Is there more than one sold form of hypo?

Reporter ____________________ Date ____________________

Team Members ____________________

3

5

page 62

Problem: Does exchange occur between the solution and the crystal form in a saturated solution?

Hypotheses:

(1) No evidence can be collected to show exchange between crystals and solution.

(2) If an exchange does occur between the crystals and the solution, there may be an observable change in the contours of the crystal surface.

Attack: Prepare a saturated solution of potassium aluminum sulfate (alum). Seal it in a beaker with undissolved crystals in the bottom. Set the beaker someplace where the temperature is constant. Observe the beaker every day for several days. Note any change in the crystal surface.

Materials:

10 g of potassium aluminum sulfate (alum)
250-ml beaker
stirring rod
graduated cylinder
rubber band
8-cm square of plastic wrap

Observations:

If fairly large crystals are available, they can be piled up in a deliberate way so that the contours are pronounced. The illustration on page 63 of the text can be used as an example. If the experiment can be done in a small bottle with a cap, a solid mass of joined crystals can be allowed to form on the bottom, and the bottle can then be turned on its side. If the crystal mass moves in response to gravity as well as changes shape, the student can conclude that an exchange does occur between crystals and solutions.

Suggest that students make a crude sketch of the crystals on the day the experiment is initiated and an additional sketch after several days.

Questions:

1. Why must temperature be controlled for this experiment?

The students may not know, because they have not formally studied the relation of solubility to temperature. Still it is worth asking. The answer is that temperature affects solubility.

2. Why should the container be covered?

It should be covered to prevent evaporation and to prevent impurities from entering.

3. Is this a controlled experiment? Explain.

In the sense of effort to control conditions, it is a controlled experiment.

4. Did you observe evidence of change in the crystal surface?

Since changes may be very slight, student reports may conflict.

5. Relate the idea of equilibrium to the two theories of matter. Which theory gives the best basis for explaining equilibrium?

Equilibrium is the idea that equal but opposite processes, in this case dissolving and crystallizing, are going on. At one point on a crystal a particle may dissolve; at another point a particle may crystallize.

Conclusions and suggestions for further investigations:

This is another situation where indirect evidence is the best that can be obtained. If a student has observed a distinct change in the crystal surface, then he has justification for concluding that an invisible exchange occurred between solid and solution. If he can cause the amount of solid to increase or decrease noticeably, he can conclude that the equilibrium has been upset.

Further investigation: Vary a condition such as temperature to see what happens to the quantity of observable solid.

Reporter ______________________ Date ______________________ 3 6 page 65

Team Members ______________________

Problem: What effect does temperature have on the solubility of substances?

Hypotheses:

(1) As the temperature of a solvent is raised, more solute can be dissolved in it up to the point of saturation.
(2) All substances will show the same response to temperature change.
(3) Each substance will show a unique response to temperature change.

Attack: Start with water near 0°C. Add a measured amount of solute and see if it will dissolve at that temperature. If it does add another measured amount. If it does not dissolve, carefully and slowly warm the solution to a temperature at which it does dissolve; then record the temperature and add a second or third measured sample.

Materials:

- 17 labels
- 17 small bottles or vials with caps
- 3 250-ml beakers
- heat source
- 20-by-150-mm test tube
- 10-ml graduated cylinder
- test tube holder
- ringstand, ring, and asbestos pad
- test tube rack
- thermometer
- one-hole stopper
- ice
- chemicals (see text)

Observations:

	Substances	Potassium Nitrate	Ammonium Chloride	Potassium Chlorate	Sodium Sulfate
	Volume of water used	10 ml	10 ml	10 ml	10 ml
	Mass of samples	5g	1g	1g	2g
First Sample	Dissolving Temperature	36°C	1°C	28°C	10°C
	Volume after dissolving	11.6 ml	—	—	—
Second Sample	Dissolving Temperature	60°C	1°C	55°C	17°C
	Volume after dissolving	14.2 ml	—	—	—
Third Sample	Dissolving Temperature	75°C	5°C	70°C	23°C
	Volume after dissolving	16.0 ml	—	—	—
Fourth Sample	Dissolving Temperature	—	24°C	80°C	27°C
	Volume after dissolving	—	—	12.0 ml	—
Fifth Sample	Dissolving Temperature	—	38°C	—	33°C
	Volume after dissolving	—	14.0 ml	—	—
Final Volume		16.0 ml	14.0 ml	12.0 ml	—
Final Mass (Water + solute)		25g	15g	14g	18g

Questions:

1. What effect does temperature have on the solubility of the substances investigated?

As the temperature went up, the solubility increased. The effect was different from substance to substance.

2. What effect would evaporation of some of the water have on your results? How can you use your data to check on whether significant evaporation occurred?

Evaporation would cause a volume and weight loss. It could also make solubility seem to be less than it really is.

3. What happens to the density of the solutions as the amount of dissolved solute and the temperature both rise?

Addition of solute will increase the density so it is higher than that of pure water. Each addition of solute will make it higher.

4. Use the two theories for matter in an attempt to interpret what you have observed in this experiment.

Particles of water contact the particles in the solute crystals and seem to pry them out of the crystal.

Conclusions and suggestions for further investigations:

An increase in temperature increases the solubility of the salts studied. The increase in solubility is different for each substance.

Further investigations: (1) Observe crystallization both from solution and from supercooling. (2) Observe dissolving and crystallization under a microscope.

Reporter ______________________ Date ________________

Team Members ____

Problem: Do some solids cool their surroundings as they dissolve?

Attack: Dissolve a number of substances in room temperature water and note what happens to its temperature.

Hypotheses:

(1) The solute may not affect the temperature of the solvent.
(2) The solute may cause the temperature to rise.
(3) The solute may cause the temperature to drop.

Materials:

- 20-by-150-mm test tubes
- teaspoon
- crystal model built with marbles and wax
- 250-ml beaker
- mortar and pestle
- ringstand, ring, and asbestos pad
- source of heat
- substances to test
- test tube rack
- 10-ml graduated cylinder
- test tube holder
- water

Observations:

Substances	Ammonium chloride	Potassium nitrate	Sodium sulfate	Copper sulfate
Initial volume of water	10 ml	10 ml	10 ml	10 ml
Initial temperature of water	25°C	25°C	25°C	25°C
Final temperature of solution	LOWER THAN INITIAL *	LOWER THAN INITIAL *	SLIGHT RISE ABOVE INITIAL *	LOWER THAN INITIAL *

* THE FINAL TEMPATURE WILL DEPEND ON THE QUANITY OF SOLUTE ADDED.

Description of copper sulfate before and after heating:

The crystal is blue and regular in shape before heating. After heating, it becomes a white powder.

Description of marble model during heating:

The marble model falls apart during heating. This raises the question of whether something similar occurs when real crystals dissolve.

Questions:

1. If heat was taken in as the solute dissolved would you expect the heat to reappear as the substance crystallized from solution?

Yes, if you believe in the conservation of heat. This was observed in the hypo experiment.

2. Relate what you have observed in this experiment to what you observed in Experiment 3–4 with hypo.

The heating of the hypo solution suggests that heat or temperature affects solution formation. The rise in temperature when the hypo crystallizes suggests that the heat is, somehow, in the solution.

3. Is there any relationship between what you observed in this experiment and what you observed in Experiment 3–6?

In Experiment 3–6, the temperature is deliberately varied to see what effect it has on solubility. In this experiment, heat is not added, so that we can see if the solution process itself causes any change in temperature.

4. Attempt to relate the observations of this experiment to the two theories for matter.

If matter is composed of tiny particles, then these particles can be moved apart (as in dissolving) or brought back together (as in recrystallization). Heat seems to be an important associated factor. It would be very difficult to explain our observations with solutions on the basis of the continuous theory of matter, other than to say that heat helps one kind of matter intermingle with another.

Conclusions and suggestions for further investigations:

Temperature changes and heat are a part of solution formation and crystal formation. Students may hypothesize that heat that is absorbed when crystals dissolve reappears when they separate from solution, and that heat that this is given off when crystals dissolve must be replaced when the crystals reform.

Further investigation: Test these hypotheses with more precise, quantitative experiments. Such experiments anticipate the work of Chapter 5.

Reporter ______________________ Date ______________________

Team Members ______________________

Problem: Is the volume of a solution always equal to the sum of the volume of its ingredients?

Hypotheses:

(1) The combined volume will be the sum of the separate volumes.
(2) The combined volume will be less than the sum of the separate volumes.
(3) The combined volume will be more than the sum of the separate volumes.

Attack: Very carefully measure and mix a variety of proportions of alcohol and water and compare the sum of separate volumes with the measured volume of the mixture. If the mixture volume becomes too large, remove half and continue to add water to reduce the percentage of alcohol.

Materials:

100-ml graduated cylinder
2 smaller graduated cylinders readable to 0.1 ml
ethyl alcohol
water
thermometer (optional)

Observations:

Volume of alcohol added	Total volume of alcohol	Volume of water added	Total volume of water	Sum of separate volumes	Percentage of alcohol by original volume	Volume together
27 ml	27 ml	3 ml	3 ml	30 ml	90%	29 ml
5	32	5	8	40	80	39
10	42	10	18	60	70	58
0	42	10	28	70	60	66
0	42	14	42	84	50	80

Discard one-half of the mixture and use the table below to continue changing percentages.

0	21	42	63	84	25	80
0	21	21	84	105	20	100

Discard one-half of the mixture and use the table below to continue changing percentages.

0	10.5	52.5	94.5	105	10	100

Questions:

1. Which of the possibilities that could be identified as hypotheses actually happened?

The volume of the solution is less than the sum of the volume of its ingredients.

2. This experiment is with a liquid-in-liquid solution. Would the results be the same for a solid in a liquid?

It would depend on the solid. Sugar, for example, and water show the same reduced volume as alcohol and water.

3. Which theory offers a better explanation for your observations? Why?

Particles might be occupying spaces between other particles. Actually, a chemical union may also occur that modifies the number of particles.

4. If particles of solute and solvent were about the same size, what would you predict for the volume of the mixture? If the particles varied greatly in size, what would you predict?

Particles of great difference in size could pack to reduce the volume, while particles of equal size would not permit a similar efficient packing. See illustration in Chapter 5, page 103 of the text.

Conclusions and suggestions for further investigations:

Ideally, students will realize that the changes in volume and temperature in these last two experiments may be indicators of interaction between the substances. The experiment should indicate to them that the final volume is not necessarily the sum of the initial volumes when two materials are put together in a solution.

Further investigation: Study volumes for many other substances in water, including solids and gases.

Reporter ____________________ Date ____________________

Team Members ____________________

Problem: What is the effect of the rate of crystal formation on the size of the crystals formed using sulfur?

Hypotheses:

If matter is composed of numerous tiny particles, then large crystals of sulfur should form as more and more sulfur particles are deposited upon a seed. The size of the crystals will depend on the rate of growth.

Attack: Prepare a saturated solution of sulfur in carbon disulfide. Divide the solution into two parts. Allow one solution to evaporate rapidly. The other solution should evaporate as slowly as possible.

(Teacher's note: The solubility of monoclinic sulfur is much higher than that of roll sulfur.)

CAUTION: Keep carbon disulfide away from heat and open flame.

Materials:

pieces of roll sulfur
20 ml of carbon disulfide
test tube
stopper for test tube
2 watch glasses
150-ml beaker

Observations:

Small crystals form on the watch glass before the period ends. By the next day larger crystals have formed in the covered beaker.

Questions:

1. Are the results of this experiment consistent with the prediction that growing crystals slowly will produce fewer and larger crystals than growing them rapidly?

Yes, it definitely shows that slow growth produces large crystals.

2. From your knowledge of solubility, explain why temperature needs to be carefully controlled when crystals are grown.

Raising the temperature of a solution in which a crystal is growing will cause the crystal to dissolve, since most solids are more soluble at higher temperatures.

3. Could you use marbles to build a model that has a shape similar to the sulfur crystals?

Yes, it is quite easy to do. Suggest that students try to build one.

4. How do the crystals grown in this experiment compare with the forms of sulfur examined in Experiment 2–2?

They are identical to those obtained in Experiment 2–2 except for size.

Conclusions and suggestions for further investigations:

Slow growth seems to produce larger and more perfectly shaped crystals than does a more rapid production. The regular, organized appearance of crystals suggests that in their formation particles have been carefully and regularly placed.

Further investigation: Find out whether there is a size limit to sulfur crystals produced under controlled conditions.

Reporter ______________________ Date ______________________

Team Members ______________________

Problem: What is the effect of the rate of crystal formation on the size of the crystals formed using copper sulfate?

Hypotheses:

(1) Rapid crystal formation results in many more smaller crystals.
(2) If sufficient time is allowed, large crystals of copper sulfate should be produced by the deposit of particles upon a few seed crystals.

Attack: Prepare a hot, saturated solution of copper sulfate in water. Divide into three parts. Cool the three parts at different rates.

CAUTION: Do not boil the solution of copper sulfate.

Materials:

- 20 g of crushed copper sulfate
- source of heat
- test tube holder
- stirring rod
- 20-by-150-mm test tube
- 3 13-by-100-mm test tubes
- 2 beakers
- test tube rack
- hot water
- ice

Observations:

(1) The test tube of hot saturated copper sulfate solution that was plunged into ice water contained hundreds of small copper sulfate crystals. The number was so great that many of the crystals stuck together.
(2) The solution cooled at room temperature produced a large number of medium-sized crystals, but not so many as in the test tube cooled in ice.
(3) The test tube of solution allowed to cool very slowly in warm water produced an even smaller number of even larger crystals.

Questions:

1. Are your observations consistent with your predictions?

Yes, slow growth of crystals produces larger, more perfect ones.

2. How does the cooling rate affect the size of crystals?

The faster the cooling, the smaller the crystals.

3. Would you say that sulfur particles and copper sulfate particles are the same shape? Explain.

They are similar, but not exactly alike. Both are rhombic in general shape.

4. Which theory offers the best explanation for the observations in this experiment and in Experiment 4–1? Why?

The particle theory offers the better basis for explanation. Relate this question to the text discussion at bottom of page 88.

Conclusions and suggestions for further investigations:

(1) Crystals appear to build up as a result of the assembly of many tiny particles in a regular pattern.

(2) The rate of growth affects crystal size—the faster the rate of formation, the smaller and less perfect the final crystals. The more slowly the crystal forms, the larger it may become and the more perfect its shape. An explanation for this is that more time is needed for solute particles to wander into position on a single large crystal compared with the hasty collection into smaller crystals when time is short.

Further investigation: Use other substances in a repeat of this same experiment.

Reporter ______________________ Date ______________

Team Members ______________________________

4
3

page 79

Problem: What conditions must exist for large crystals to form?

Hypotheses:

Large crystals may be formed on a seed of the solute in a saturated solution in which the solvent is removed slowly and the temperature is kept fairly constant.

Attack: Prepare a saturated solution of potassium aluminum alum. Allow a small part of it to evaporate to obtain a seed crystal. Use nylon thread to suspend the seed crystal in the saturated solution. Set the system where the temperature is fairly constant. Observe it at least once a day for about a week.

Materials:

alum (potassium aluminum sulfate)
nylon thread
20-by-150-mm test tube
watch glass
water

Observations:

Day 1:	*Crystal is suspended in the test tube.*
Day 2:	*Crystal has grown slightly.*
Day 4:	*More growth is evident.*

Students may have trouble suspending the seed crystal. Be sure to use nylon thread instead of single filament nylon fishline.

Questions:

1. Why is it necessary to keep the temperature constant in this experiment? What would happen if it was not kept constant?

Cooling may produce supersaturation, which causes many small crystals to form. Heating may dissolve the seed or the grown crystal.

2. How can you control the evaporation rate of the solvent?

Use a cover on the container, or keep the system at a low temperature.

3. How does the shape of alum crystals compare with the shapes of sulfur and copper sulfate crystals?

It is quite different. From one perspective they look square. From another they look like double pyramids.

4. Is the growth of your crystal consistent with the prediction that slow growth produces large crystals?

Yes.

Conclusions and suggestions for further investigations:

If the temperature is held constant and the growth is slow enough, a quite sizeable, perfect crystal of alum can be grown.

Further investigation: Find out whether crystals of two different solutes (alum and copper sulfate) can be grown from the same solution if it is saturated with both solutes.

Reporter ______________________ Date ______________________

Team Members ____

Problem: Will a substance deposit from solution onto a crystal of another substance?

Hypotheses:

(1) A solute will crystallize on any kind of seed.

(2) A solute will not crystallize on any kind of seed, only on one of the same substance.

(3) A solute will form crystals on any seed which has the right shape.

Attack: Select a substance whose crystalline form is similar to that of potassium aluminum sulfate and another that has a different crystalline structure. Suspend an alum crystal in a saturated solution of each. Observe each solution daily for a week or more.

Materials:

2 seed crystals of potassium aluminum sulfate
nylon thread
6 g of potassium chromium sulfate
saturated solution of copper sulfate
2 20-by-150-mm test tubes
2 stoppers for test tubes
test tube rack

Observations:

(1) The aluminum alum crystal dissolves in the copper sulfate solution.

(2) The chrome alum grows on the aluminum alum crystal.

(3) The boundary between aluminum alum and chrome alum appears blurred.

Questions:

1. Which materials seem to be similar enough to allow growth of one substance on a crystal of the other?

Aluminum alum and chrome alum.

2. If the crystals are made of particles, what does this experiment suggest about particles of various substances?

Particles of two different kinds of substance may be similar enough to "grow together" in some cases and not similar enough in others.

3. What explanation can you offer for the lack of a clear line between the two substances in the one crystal?

Some seed crystal particles were dissolving while solute particles were crystallizing.

4. Can two solutes exist in the same sample of solvent?

Yes, since the alum dissolved into the copper sulfate solution.

5. What do you predict might happen during crystallization from a solution that contains solutes that do not grow on each other's crystals?

Crystals of each will form separately when the solution becomes saturated in that solute.

Conclusions and suggestions for further investigations:

If particles are assumed, then we can suggest as a conclusion to this experiment that in some cases particles of one substance can fit into or onto particles of another. The two alums are compatible. In other cases, the particles are not compatible in size, shape, or some other property and thus will not fit together.

Further investigation: Experiment with the separation of substances from a solution that contains several kinds of solutes. Sea water, if available, could be the material to study.

Reporter ______________________ Date ______________

Team Members ______________________________

Problem: Crystals form as metals are deposited from a solution by chemical reaction. Do these crystals provide evidence of the structure of matter?

Hypotheses:

Metallic crystals, like other crystals, should show evidence of a particle structure.

Attack: Bring pieces of metal in contact with a solution of a compound that contains another metal. As reaction occurs and the second metal appears, examine the deposit very carefully for evidence of crystal formation. Use a magnifier and a microscope as well as the unaided eye.

Supplementary demonstration: Put a droplet of mercury in some $AgNO_3$ solution in a test tube. Some remarkably fine silver crystals will result if the solution is left undisturbed for several days.

Materials:

5 g of crushed copper sulfate	4 13-by-100-mm test tubes
silver nitrate solution	150-ml beaker
iron nail	test tube rack
mossy zinc	magnifier
magnesium ribbon	microscope
copper wire	8 glass slides
distilled water	

Observations:

	Deposit on iron nail	Deposit on magnesium	Deposit on mossy zinc	Deposit on copper wire	Residue after evaporation
Unaided eye	COPPER DEPOSIT WILL BE A RED-ORANGE COLOR. IT IS IN FORM OF FLAKES AND DOES NOT LOOK CRYSTALLINE.			SILVERY SWELLING WILL BUILD UPON THE WIRE.	TWO SUBSTANCES MAY BE IDENTIFIABLE.
Magnifier	THE CRYSTALLINE NATURE WILL BE MORE APPARENT.				
Microscope	A REGULAR PATTERN MAY BECOME EVIDENT ALTHOUGH IT IS NOT VERY EXTENSIVE.				IF TWO SUBSTANCES ARE PRESENT, THE CRYSTALS' DIFFERENCES WILL BE MORE APPARENT.

Questions:

1. In which instances does copper seem to be the deposited substance?

Copper seems to be on the iron nail, the magnesium, and the zinc.

2. What evidence is there for crystalline form in the deposits?

Very little evidence. The fragile nature of the deposit makes it difficult to examine carefully.

3. Is this experiment a source of evidence for one of the two theories for matter?

It gives limited evidence for crystals and the particle theory, but can be construed as suggesting and supporting the continuous theory.

4. From your general knowledge of metals, do they seem to have some continuous properties?

Their ability to be bent, drawn into wire, and hammered into sheets makes them very different from other crystalline substances.

Conclusions and suggestions for further investigations:

The experiment does not add appreciably to the particle theory. If students accept the particle theory, they must invent ways for it to explain the nature of metals.

Further investigation: Examine other metals for crystalline nature.

Reporter ______________________ Date ______________ 4 6 page 83

Team Members ______________________________________

Problem: Will examination of the crystals formed by precipitation provide evidence for the structure of matter?

Hypotheses:

All crystals should have a regular appearance that suggests a particle structure of matter.

Attack: Observe the formation of the crystals under a microscope by carefully pushing drops of two solutions together.

Materials:

3 clean glass slides
clean stirring rod
microscope
saturated solutions of barium chloride, calcium chloride, magnesium sulfate, and strontium chloride

Observations:

The particles are quite tiny, but regular in shape. If the crystals form slowly, the students may report growth as an observable fact. The shape of the crystals is maintained during their growth.

Questions:

1. Why is it important to have clean glass slides and a clean stirring rod for use in this experiment?

Under the microscope, tiny bits of dirt look quite sizeable and obscure what you want to see. Students could mistake them for the crystals.

2. Do the visible crystals change in appearance when the water has evaporated?

Yes, they grow larger.

3. Examine the dry deposits carefully. Is there any evidence for a second or third crystal form? Is there a reason why more than one kind of crystal might be present?

It is possible for crystals of four substances to be present.

4. Do the observations of this experiment provide further evidence favoring one of the two theories for the structure of matter?

This experiment may lead students to suggest that the two original substances exchange subparticles to create new particles. The particle theory can explain such an exchange.

Conclusions and suggestions for further investigations:

The regular shape of the particles seen under the microscope is consistent with the particle theory.

Further investigation: Try to separate and identify the four substances referred to in question 3.

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Team Members ______________________________________

Problem: What additional information on crystal formation can be obtained by observing the freezing of a melted substance?

Hypotheses:

Crystals which form during cooling of a substance show the same evidence of particle structure as those formed by other methods.

Attack: Warm a very small amount of salol on a glass slide until it melts. Then observe it under a microscope or magnifier as it cools and crystallizes.

Materials:

- glass slide
- microscope or magnifier
- spoon or spatula
- salol (phenyl salicylate)
- benzoic acid

Observations:

Salol and benzoic acid both tend to supercool, so disturbance of the drop and sudden crystal formation may be the only observation. Suggest that students try the experiment several times. The crystals will be in the form of long needles that fan out from the point where formation starts.

If you have a pair of polaroid lenses, view the crystals when placed between them. As one lens is rotated, a rainbow of colors becomes evident in the crystal deposit.

Questions:

1. How does the cooling rate seem to affect the rate of crystallizing?

Faster cooling results in faster crystallization and smaller, more crowded crystals.

2. Do you observe any evidence that supercooling takes place in the drop?

Very likely.

3. When the substance has solidified does it have a clearly crystalline appearance?

Yes, in the form of needles radiating out from a point.

4. Does this experiment cause you to modify your views about which theory for matter is the better one?

No, it should reinforce the particle theory.

Conclusions and suggestions for further investigations:

Both salol and benzoic acid show enough regularity to suggest crystalline nature, which indicates that crystals form as substances cool and freeze.

Further investigation: Try to control the temperature and the rate of crystal formation so that a large crystal could be formed.

Reporter ______________________ Date ______________

Team Members ______________________________________

Problem: What is the distinction between temperature and heat?

Hypotheses:

(1) Temperature and heat are synonyms.
(2) Temperature is a level of intensity, while heat is a quantity transferred from one substance to another.

Attack: Use a burner with fairly intense and constant heat to heat a large iron nail and 200 ml of water in a beaker. Heat the water and the nail for the same length of time. Test the temperature of the nail by touching it to a piece of paper. Test the temperature of the water with your finger.

Materials:

250-ml beaker
200 ml of water
iron nail
forceps or pliers
source of heat
ringstand, ring, and asbestos pad
paper

Observations:

The heated nail will ignite the paper, but will not warm the water appreciably.

Questions:

1. Did both substances absorb heat from the burner?

Yes.

2. How did the manner of absorption differ?

The nail got very hot, but the water temperature changed only slightly.

3. Distinguish between intensity of heat and quantity of heat.

The nail and the water each received the same quantity of heat, since they were heated by the same burner for the same length of time. However, a much more intense change in temperature was produced in the nail than in the water.

Conclusions and suggestions for further investigations:

Temperature is a way of expressing how hot an object is compared to another object. Heat, by contrast, is something that can change the temperature of an object that absorbs it. How much a given amount of heat changes the temperature of an object depends on the amount of matter in the object. The less matter, the greater the temperature change.

Further investigation: Try to produce an intense change in a small quantity of a substance and compare it with a less intense change in a large amount of the same substance.

Reporter ______________________ Date ______________

Team Members ______________________________________

Problem: Is the human nervous system when used directly a reliable source for sensing heat and temperature?

Hypotheses:

Students may argue about the reliability of their senses, some saying yes and others no. Still others may recognize the need to get data by experiment.

Attack: Expose your senses to different heat and temperature conditions. Use three containers of water—one quite cold, one at room temperature, and one quite warm. Put your hands into all three at separate intervals.

Materials:

3 widemouth containers with 1000-ml capacity
quantities of cold, hot, and room temperature water

Observations:

The hand that had been in hot water sensed the middle temperature as cold. The hand that had been in cold water sensed the middle temperature as warm.

Questions:

1. Are the nerves in your hands reliable temperature sensors? Explain.

No, they are influenced by temperatures they have recently experienced.

2. What other parts of the body might be better temperature sensors than your hands?

The upper lip is quite sensitive to slight temperature change. The inside of the wrist is another sensitive area.

Conclusions and suggestions for further investigations:

The human nervous system is of limited usefulness in sensing temperature or heat. We need instruments to aid and extend our senses when we attempt to measure temperature and heat.

Reporter ______________________ Date ______________

Team Members ____________________________________

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3

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Problem: What response to heat does matter make that might provide a basis for measuring temperature?

Hypotheses:

Matter changes in size when heated. It might expand or it might shrink.

Attack: Prepare a system that allows the expansion of a heated sample of water to occur only along a narrow tube.

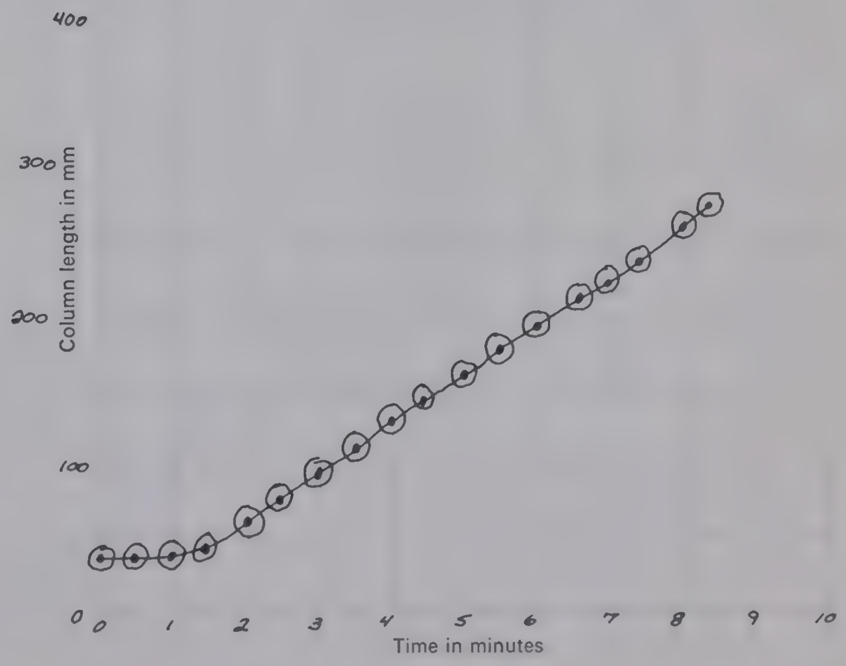
CAUTION: Follow your teacher's instructions on inserting glass tubing into the stopper.

Materials:

30-cm length of glass capillary tubing
test tube
one-hole stopper to fit test tube
250-ml beaker
water
candle
metric ruler

Observations:

Elapsed time in minutes	Column length in mm
0	30
0.5	34
1.0	40
1.5	49
2.0	55
2.5	71
3.0	98
3.5	109
4.0	125
4.5	140
5.0	155
5.5	175
6.0	190
6.5	214
7.0	223
7.5	241
8.0	265
8.5	275



Questions:

1. What limitations prevent the general use of this thermometer as a temperature-sensing device?

Water will freeze, boil, or evaporate. Test tube must absorb or discharge much heat to change its temperature.

2. Does the temperature (intensity of heat) seem to be related to the amount of heat that is put into an object (like the water thermometer)?

Yes, the water expanded steadily as heat was added uniformly.

3. Why does the addition of heat cause the water to expand?

Heat may fill spaces between particles, may make particles become larger, or may make them move around. Any of these possibilities would cause the particles to take up more space.

4. From your general experience can you identify other liquids that would be better than water for use in thermometers?

Oil, glycerine, alcohol, mercury—liquids that do not freeze in the range of usually experienced temperatures.

Conclusions and suggestions for further investigations:

Some students may suggest increased particle motion as the explanation, for most have been exposed to the theory. It is not a better explanation at this point, but it would be difficult to try to talk them out of it. Whatever their conclusions, they should be consistent with observations and compatible with the model for the structure of matter.

Further investigations: (1) Find out if all liquids expand when heated in the same manner. (2) Study the expansion of solutions.

Reporter ______________________ Date ______________

Team Members ______________________________________

Problem: What happens to the temperature of a sample of ice as it is heated, melted, and finally boiled?

Hypotheses:

(1) The temperature will rise constantly.
(2) The temperature will rise erratically.
(3) The temperature will not rise at all for some time.

Attack: Place a sample of ice in a can and heat it with a moderate, steady source of heat. Take the temperature of the sample continuously and record the temperature at regular intervals until the water has boiled away. Prepare a graph from your results.

Materials:

small metal can	stirring rod
ringstand, ring, and asbestos pad	source of heat
thermometer	ice cubes
	paper towel or cloth

Observations:

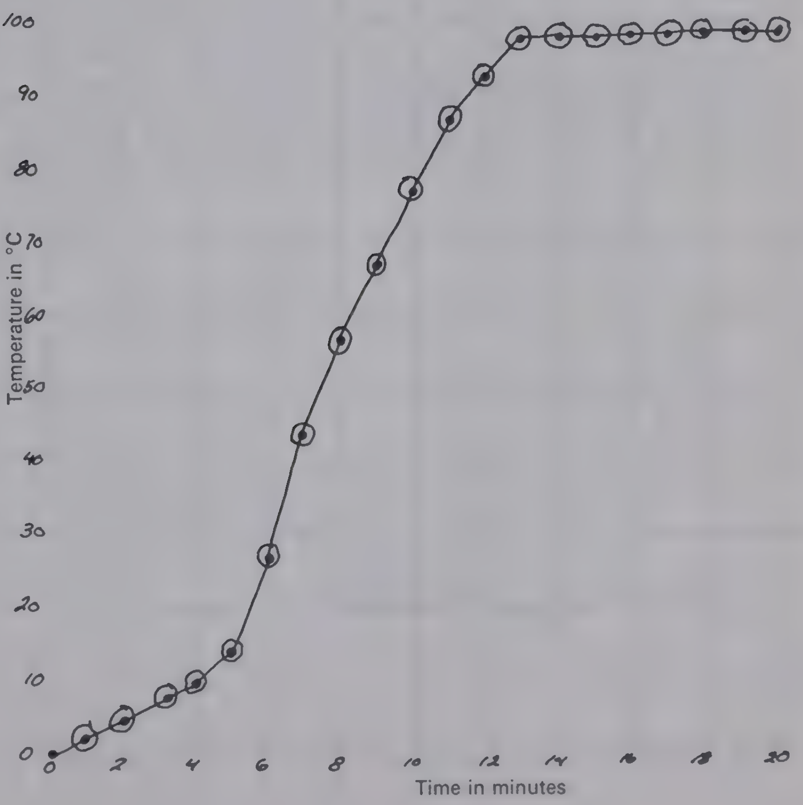
Heat source was a Bunsen burner set at a very low level. Melted ice had a volume of 110 ml.

Time in minutes	Temperature in °C.
0	0
1	2
2	5
3	8
4	10
5	15
6	27
7	44
8	56
9	68
10	78
11	88
12	94
13	98
14	98
15	98
16	98
17	98
18	
19	
20	
21	
22	
23	
24	
25	

ICE DISAPPEARS RAPIDLY (0–4 minutes)

ICE COMPLETELY GONE (4–5 minutes)

WATER BOILS (12–13 minutes)



Questions:

1. What is the melting temperature for ice according to your experiment?

It melts in a range from 0°C to about 10°C. Note that as long as ice is present, the rise in temperature is slow. When the ice is gone, the temperature rise is much faster.

2. What is the boiling temperature for water according to your experiment?

In the experiment recorded on the previous page, boiling occurred at 98°C.

3. Why might the values that you obtain be different from the accepted values for the melting and boiling points of water?

The thermometer may not read the correct temperature. For boiling, the atmospheric conditions of the experiment may cause the boiling point to vary.

4. Is heat absorbed by water as it melts and boils? Which heat theory might explain where heat goes as water melts and boils?

At both melting and boiling points, heat seems to be doing something more than raising the temperature. Under the particle motion theory the heat may serve to push the particles farther apart or help them move out of fixed positions. Under the caloric fluid theory, the fluid attaches to the particles and pushes them apart as they melt or vaporize.

Conclusions and suggestions for further investigations:

The application of heat to a mixture of ice and water causes the temperature to rise from 0°C to 98°C. As long as ice is present some of the heat seems to go into melting it. When the ice is gone, all the heat seems to go into causing a temperature rise. At boiling, the continued addition of heat does not raise the temperature. Instead it may be going into the conversion of liquid water to water vapor.

Further investigations: (1) Deliberately vary the rate at which heat is applied. (2) Reverse the experiment. (3) Study other substances that melt readily.

Reporter ____________________ Date ____________________

Team Members ____

Supplementary
Experiment for
Chapter 5
(see p. 106)

Problem: Does the beginning temperature affect the freezing time of a water sample?

Attack: In freezing weather place samples of hot and cold water outdoors where they will cool and freeze. Observe and record the temperatures of the samples at regular time intervals. Prepare a graph from your results.

Hypotheses:

(1) Cold water will freeze faster.
(2) Warm water will freeze faster.
(3) The beginning temperature will not change the freezing rate.

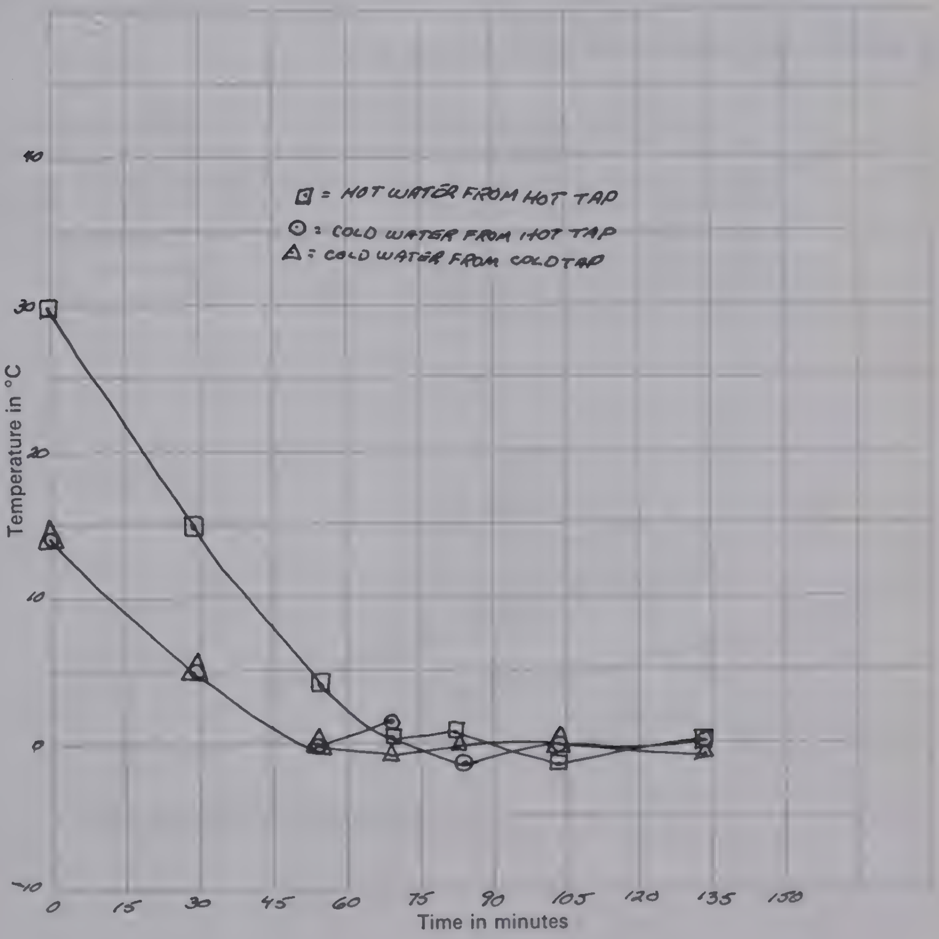
Materials:

containers to hold water samples
water samples at several initial temperatures that are above freezing
thermometer for each sample

Observations:

Data for this type of experiment is given in Table 5–2, page 107 of the text.

Time in minutes	Temperature in °C	
0	14.4	COLD WATER FROM HOT TAP
30	5.0	
55	0.0	
70	1.0	
85	-1.8	
105	0.0	
135	-0.5	
0	30.0	HOT WATER FROM HOT TAP
30	15.0	
55	4.4	
70	1.2	
85	0.5	
105	-1.4	
135	0.0	
0	14.4	COLD WATER FROM COLD TAP
30	5.0	
55	0.0	
70	-0.5	
85	0.0	
105	0.0	
135	0.0	



Questions:

1. Is this experiment in any way like Experiment 3–4 in which you observed a supersaturated solution of hypo?

It is possible that supercooling can occur. Usually, however, it will not.

2. How is the graph for the data of this experiment alike and different from the graph for Experiment 5–4?

It is the opposite process—uniform cooling, then levelling. After freezing is complete, the graph may again begin to drop.

3. Did you observe any evidence that indicated that your water samples were not pure water?

Air bubbles might separate during hard freezing and be trapped in the ice as it forms.

4. Are the hypotheses you stated for this experiment correct? Explain your thinking.

The amount of heat to be lost will affect the period of cooling to the freezing point. The rate of cooling is linked with the starting temperature.

Conclusions and suggestions for further investigations:

This is a difficult experiment and the results are not often conclusive. In a moist environment, frost crystals in the air may seed the specimen before supercooling occurs. Unless the sample is aerated, the warm water will probably contain less dissolved gases, and this may influence the formation of ice. Since the latent heat of fusion of ice is high in comparison to the specific heat of water, the difference in initial water temperature is not a large factor (as much heat must be removed to freeze one gram of water as to cool it to freezing from 80°C).

Reporter ______________________ Date ______________________

Team Members ______________________

Problem: How will the time–temperature relationship change when the size of water samples to be heated is changed?

Hypotheses:

Increasing the quantity of sample to be heated should lower the rate of temperature change and increase the time to reach the same temperature.

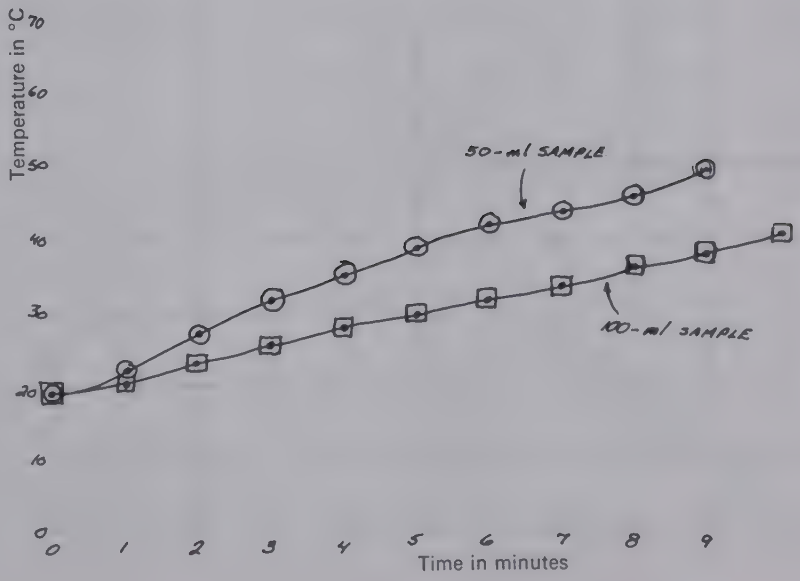
Attack: Use a heat source that gives a steady supply of heat. Apply the heat to water samples of several sizes and take the temperature of the samples at regular intervals. Use your results to prepare a graph.

Materials:

small metal can
ringstand, ring, and asbestos pad
thermometer
stirring rod
source of heat

Observations:

	Time in minutes	Temperature in °C
50-ml sample	0	20.0
	1	24.0
	2	28.0
	3	31.5
	4	35.0
	5	38.0
	6	41.0
	7	43.5
	8	46.0
	9	48.0
100-ml sample	0	20.0
	1	22.0
	2	24.0
	3	26.0
	4	28.0
	5	30.0
	6	32.0
	7	34.0
	8	36.0
	9	38.0
	10	40.0



Questions:

1. What evidence does this experiment provide to indicate that the heat source does supply heat at a constant rate?

Both curves are relatively straight lines.

2. Suggest a method for measuring heat based on this experiment.

Since temperature change depends upon the amount of substance heated and on the heat added, we should be able to measure heat by determining the change of temperature of a standard amount of a standard substance.

3. Does all heat go into the water sample? Explain.

No. The can, the supporting apparatus, and the air that rises above the equipment are heated also.

4. Does the 100-ml sample of water require twice as much heat as the 50-ml sample to raise its temperature the same amount?

In general, yes. If the temperature rises too much, then vaporization and other losses occur.

5. Predict where the line for a 200-ml sample of water would fall on your graph.

Each temperature value should be halfway between that of the 100 ml sample and the initial temperature, if the two samples had the same initial temperature.

Conclusions and suggestions for further investigations:

If the same amount of heat is used to produce a change of temperature in different quantities of the same substance, the change in temperature will diminish as the amount of substance is increased.

Further investigation: Refine this experiment by insulating containers and by performing it with a variety of quantities of water.

Reporter ______________________ Date ______________

Team Members ______________________________________

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6
page 110

Problem: Does the material of which a container is made affect the rate of cooling of the contents?

Attack: To each container add the same amount of boiling water. Trace the cooling of the water in each by using a thermometer. Record the temperature changes at regular intervals and use the data to prepare a graph.

Hypotheses:

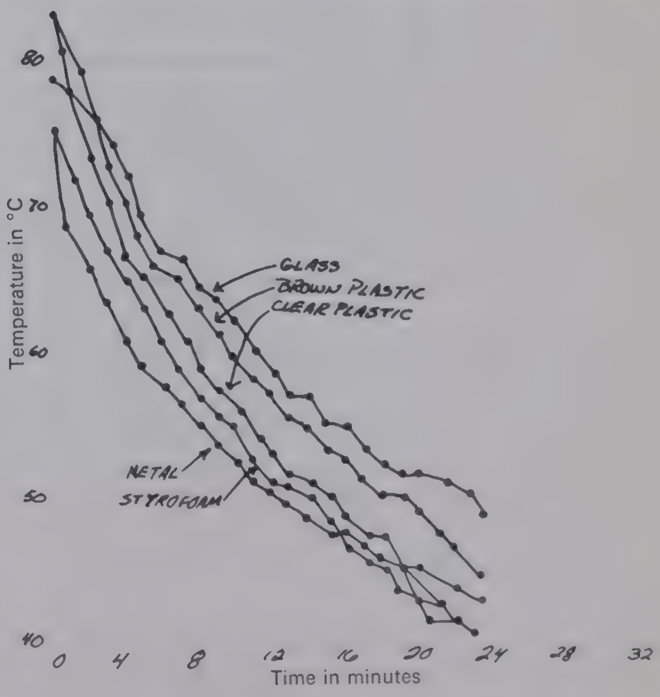
Most students will say yes, but their reasons will differ and their prediction of how it will affect the rate of cooling will differ.

Materials:

variety of containers
thermometer for each container
boiling water
graduated cylinder

Observations:

Time in minutes	Containers					
	BROWN PLASTIC	CLEAR PLASTIC	GLASS	METAL	STYROFOAM	
0	83°C	83°C	79°C	75°C	75°C	
1	79	81	78	68	72	
2	76	73	76	66	69	
3	73	70	74	63	67	
4	70	67	72	61	65	
5	68	65	69	59	63	
6	66	62	67	58	61	
7	65	61	66	57	59	
8	63	59	64	55	57	
9	61	58	63	54	56	
10	60	56	62	53	55	
11	58	54	60	52	53	
12	57	53	58	51	52	
13	56	52	56	50	51	
14	55	51	56	49	50	
15	54	50	55	48	48	
16	53	49	55	48	47	
17	51	47	54	47	46	
18	50	47	53	46	45	
19	50	45	52	45	44	
20	49	43	52	45	43	
21	48	43	51	45	42	
22	47	42	50	44	42	
23	45	41	49	43	41	



Questions:

1. What materials seem to be good heat insulators?

Soft, porous, low-density, nonmetallic substances.

2. What materials seem to be good heat conductors?

Hard, solid, dense, metallic substances.

3. Does color affect the rate of loss of heat?

Yes. If color were the only variable, the lighter colored materials would show greater heat loss. But the other variable in this experiment is the type of material used. This is a good place to discuss the significance of control.

4. Explain the difference between an insulating substance and a conducting substance by using the caloric fluid theory.

In a porous insulating substance, caloric fluid may collect in the spaces, so that there is little temperature change. Caloric fluid apparently passes through the spaces in a conducting material.

5. Would the use of covers on the containers change the rate of heat loss?

This calls for another experiment, unless the student is expected to guess.

Conclusions and suggestions for further investigations:

Heat loss in this experiment may be by any of the recognized means—conduction, convection, and radiation. The factors that govern the cooling rate are therefore quite complex. Whatever the conclusions, they should be related to the students' theory of matter and heat and should be expressed in terms of these theories.

Further investigation: Try to answer question 5.

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Team Members ______________________

Problem: How does the loss of heat compare with the loss of water from a leaking container?

Hypotheses:

(1) Water leakage and heat loss are similar.
(2) Water leakage and heat loss are not at all alike.
(3) Water leakage and heat loss are alike in some ways and different in others.

Attack: Fill a milk carton with cold water; punch a small hole in the side of the carton at a point very close to the bottom. Use a ruler to measure the leakage rate at regular time intervals.

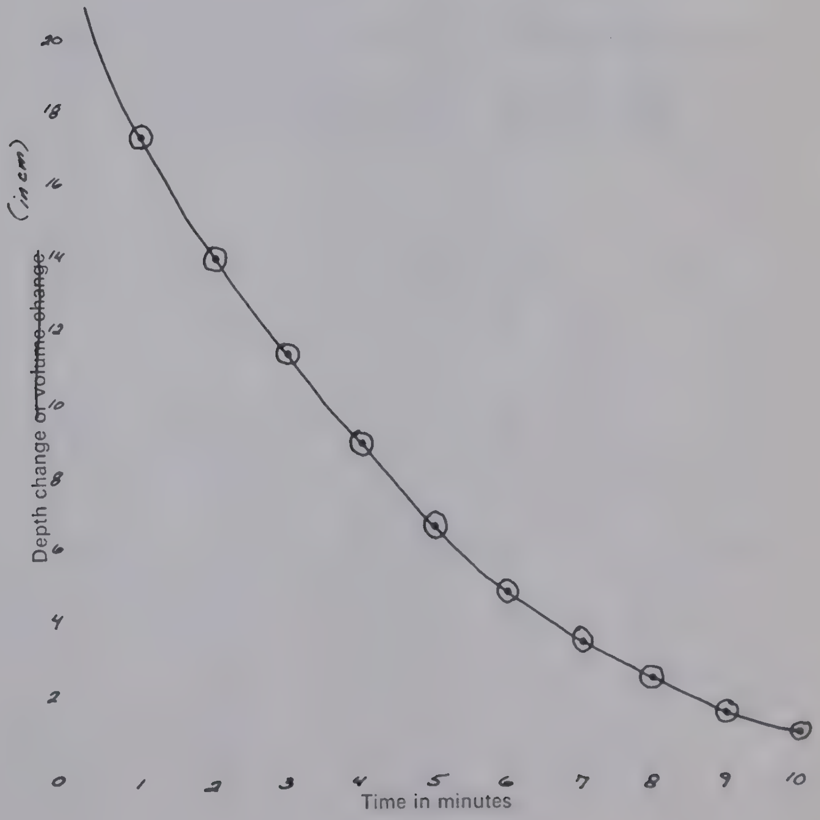
Materials:

milk carton
small nail
metric ruler
container to catch leakage
water

Observations:

A nail hole was made at the bottom edge of the side of a plastic bottle.

Time in minutes	Depth or volume change
0	24cm
1	17.5
2	14.0
3	11.2
4	8.8
5	6.5
6	4.8
7	3.5
8	2.3
9	1.6
10	1.0



Questions:

1. How does the graph for water loss compare with those for heat loss in the calorimeters?

They are similar in shape.

2. If the hole were enlarged or a second hole of the same size were made, what would happen to the rate of water loss?

The rate of water loss would increase in the beginning, but would decrease at the same rate at the end.

3. From your observations do you think that water loss and heat loss are similar?

Yes, at least in the way the rate of each changes.

4. What more can you say about the nature of heat and the nature of insulators and conductors?

Insulators do not seem to have the "leakage holes" that conductors do.

Conclusions and suggestions for further investigations:

The changing rate of water leakage from a container with a hole in it is very similar to the changing rate of heat loss from a container of hot water. As the temperature of the hot water sample drops toward room temperature, the rate of heat loss slows. As the water level in the bottle approaches the bottom, the rate of leakage slows. This might be interpreted as favoring a caloric fluid theory for heat. All containers seem to "leak" heat.

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Team Members ______________________________________

Problem: If two quantities of water at quite different temperatures are mixed, what happens to the heat in them and what will be the final temperature?

Hypotheses:

(1) The heat will distribute itself in the mixture to produce an intermediate temperature.

(2) The heat will be lost, or in some other way will not distribute itself, and the final temperature will not be predictable.

Attack: By measuring the quantity of water in each sample and the change in temperature of each, when they are mixed, expressions for the amount of heat gained and heat lost can be obtained and compared.

Materials:

2 calorimeters
2 thermometers
graduated cylinder
hot and cold water

Observations:

Trial	Vol. of cold water	Temp. of cold water	Vol. of hot water	Temp. of hot water	Total vol.	Final temp.
	a	b	c	d	e	f
1	100 ml	10°C	100 ml	78°C	200 ml	43°C
2	100	11	100	86	200	44
3	100	8	100	85	200	43
4	100	10	100	86	200	43
5	100	7	100	81	200	45
6	100	7	100	85	200	45
7	100	8	100	83	200	43
8	100	9	100	79	200	43

Calculations:

Trial	Change in temp. of cold water	Calories gained by cold water	Change in temp. of hot water	Calories given up by hot water
	f − b	a(f − b)	d − f	c(d − f)
1	33°C	3300 cal	35°C	3500 cal
2	33	3300	42	4200
3	35	3500	42	4200
4	33	3300	43	4300
5	38	3800	36	3600
6	38	3800	40	4000
7	35	3500	40	4000
8	34	3400	36	3600

Questions:

1. How does the heat lost compare with the heat gained?

The heat lost is usually greater than the heat gained. Loss to the container and to the surroundings is the probable cause. With ideal insulation, the amounts should be equal.

2. Why would you do this experiment more than once before drawing any conclusions?

If the fifth trial had been the only performance, the conclusion would be quite different from that drawn from the eight trials.

3. Predict the final temperature if 50 ml of cold water at 5°C were mixed with 100 ml of hot water at 95°C. Test your prediction by experiment.

Assume heat lost equals heat gained. Since there is only half as much cold water as hot water, the cold water would have to change in temperature twice as much as the hot water.

$$\frac{95^\circ\mathrm{C} - 5^\circ\mathrm{C}}{3} = 30^\circ\mathrm{C}$$

Hot will drop 30° to 65°C; cold will rise 60° to 65°C, if the experiment is ideally insulated.

4. What factors might lead to a consistent difference between the amount of heat lost and the amount gained?

Amount of heat absorbed by containers or thermometers; differences in calibration of thermometers; consistent pouring of hot water into cold, or vice versa.

Conclusions and suggestions for further investigations:

Most of the heat lost by the hot water is gained by the cold water.

Further investigation: Try to insulate the containers to see if the hypothesis that loss of heat to the container and the surroundings is a correct explanation of why heat lost does not equal heat gained.

Reporter ______________________ Date ______________________

Team Members ______________________

Problem: What techniques can be used to trace the exchanges of heat as samples of hot and cold water are mixed?

Attack: Measure the mass and the temperature of quantities of hot and cold water before mixing and use these values to determine heat content and to predict a final temperature for the mixture.

Hypotheses:

Students will need help with this one, although Experiment 5–9 and the tables on pages 116–117 of the text provide clues. The main point to emphasize is that the final temperature may be predicted by obtaining values for the total heat and total weight of the systems.

Materials:

2 calorimeters
2 thermometers
graduated cylinder
balance
hot and cold water

Observations:

Trial	Calorimeter wt.	Hot water + calorimeter	Hot water temp.	Mixture + calorimeter	Mixture temp.	Cold water temp.
	a	b	c	d	e	f
1	30.7g	124.1g	70.8°C	242.0g	38.2°C	12.0°C
2	30.7g	127.4g	77.0°C	208.8g	47.2°C	11.6°C
3						
4						
5						
6						

Calculations:

Trial	Wt. of hot water	Heat of hot water	Wt. of cold water	Heat of cold water	Total heat	Wt. of mixture	Predicted final temp.
	$b - a$	$(b - a)c$	$d - b$	$(d - b)f$	$(b - a)c + (d - b)f$	$d - a$	$\frac{(b - a)c + (d - b)f}{d - a}$
1	93.4g	6613 cal	117.9g	1415 cal	8028 cal	211.3g	38.0°C
2	96.7g	7446 cal	81.4g	944 cal	8390 cal	178.1g	47.1°C
3							
4							
5							
6							

Questions:

1. Why is the measurement of the water by mass a better measurement than by volume?

Mass does not change with temperature, while volume does. Remind students of Experiment 5–3.

2. What explanations can you offer for why the observed temperature and the predicted temperature are different in some trials?

Loss of heat to surroundings, reading errors, instrument errors, calculation errors.

3. If differences exist between the predicted and actual final results, can you suggest explanations? Does the experimental technique seem to cause the difference?

The arithmetic idealizes the result. The sources of error listed in question 2 can cause deviations from the ideal result.

4. Do your results indicate that heat is conserved?

The results will seldom support the idea of conservation of heat in an ideal way.

Conclusions and suggestions for further investigations:

Data about the weights and the temperatures of samples of hot and cold water can be used to predict what the final temperature will be when the samples are mixed.

Further investigation: Run additional trials to try to bring the average closer to the ideal predicted value.

Reporter ______________________ Date ______________

Team Members ______________________________________

Problem: Does heat play a part in the melting of ice? If so, is the amount of heat required a constant and predictable quantity?

Hypotheses:

Predictions can be yes or no, but some astute student may point out that ice never melts unless the surrounding temperature is higher than 0°C, which tends to eliminate the negative hypothesis.

Attack: Follow the same basic procedure as in Experiment 5–9, using ice instead of cold water for one sample. In addition try to identify the amount of heat in surplus of that necessary to warm water at 0°C to the final temperature. Then determine the amount of heat needed to melt one gram of ice.

Materials:

2 calorimeters
2 thermometers
graduated cylinder
balance
ice
hot and cold water

Observations:

Trial	Calorimeter wt.	Hot water + calorimeter wt.	Hot water temp.	Mixture and calorimeter wt.	Mixture temp.
	a	b	c	d	e
1	15g	108g	87°C	138g	53°C
2	15	93	86	133	30
3	15	113	87	158	32
4	15	107	89	144	38
5	17	109	83	145	34
6	17	101	84	141	43

Calculations:

Trial	Wt. of hot water	Heat of hot water	Wt. of cold water (ice)	Wt. of mixture	Heat of mixture	Heat to melt ice	Heat to melt 1 g of ice
	$b - a$	$(b - a)c = G$	$d - b$	$d - a$	$(d - a)e = H$	$G - H$	$\frac{(G - H)}{(d - b)}$
1	93g	8100 cal	30g	123g	6500 cal	1600 cal	53 cal
2	78	6700	40	118	3500	3200	80
3	98	8500	45	143	4500	4000	89
4	92	8500	37	129	4900	3300	89
5	92	7600	36	128	4400	3200	89
6	84	7100	40	124	5300	1800	45

Questions:

1. What average value do you get for the calories per gram of heat needed to melt ice?

For this set of student data,

$$\frac{53 + 80 + 89 + 89 + 89 + 45}{6} = 78\ \frac{\text{cal}}{\text{g}}.$$

2. Think about the freezing ice. What happens with respect to heat as the ice freezes?

According to the caloric fluid theory, the fluid comes out, permitting the particles to come together in the crystalline structure. Or, according to the particle motion theory, particles slow down and come closer together.

3. How does the amount of heat needed to melt ice compare with the amount needed to heat the melted water from the freezing to the boiling point?

Students will get as much as 80 calories per gram for the amount of heat needed to melt ice. This is 0.8 times as much as the 100 calories per gram needed to heat water from 0° to 100°C.

4. How well can the information of this experiment be fitted into the heat theories?

The experiment suggests that heat distributes evenly throughout combined samples. Any theory must help to explain where heat goes when ice melts and what happens as melting occurs.

Conclusions and suggestions for further investigations:

A definite quantity of heat goes into converting ice to water. It is much larger than the quantity needed to heat water one degree centrigrade. Student values for the heats of melting may range from 60 to 80 calories per gram.

Further investigation: Try to determine the heat of melting of another substance. Paradichlorobenzene (moth nuggets) would be a suitable substance.

Reporter ______________________ Date ______________

Team Members ____________________________________

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Problem: How do the heat capacities of other substances compare with the heat capacity of water?

Hypotheses:

(1) Water has more heat capacity than other substances.
(2) Water has less heat capacity than other substances.
(3) Heat capacities of water and other substances are the same.

Ask students to qualify their hypotheses.

Attack: Use a piece of material heated to a known temperature and then immersed in a known amount of cold water at a known temperature as a way of getting data on the exchange of heat between the hot sample and the cold water. Repeat this procedure with each sample.

Materials:

samples of metals and other substances
calorimeter
2 thermometers
cold water
container of boiling water

Observations:

	Trials					Units
Data identification	1	2	3	4	5	
Kind of substance	BRASS	IRON	COPPER	QUARTZITE	IRON	
Volume of sample (*a*)	50	40	30	50	80	ml
Mass of sample (*b*)	400	281	380	146	440	g
Temp. of hot sample (*c*)	93	92	87	92	90	°C
Mass of cold water (*d*)	102	133	99	101	107	g
Initial temp. of cold water (*e*)	11	9	14	23	12	°C
Final water temp. (*f*)	31	29	26	36	38	°C

Calculations	1	2	3	4	5	Units
DENSITY	8	7	13	2.9	5.5	g/ml
Temp. change of water $(f - e)$	20	20	12	13	26	°C
Heat gained by water $d(f - e)$	2040	2660	1200	1300	2800	cal
Temp. change of sample $(c - f)$	62	63	61	56	52	°C
Heat loss per ml of sample $\frac{d(f - e)}{a}$	40.8	65	40	26	35	cal/ml
Heat loss per ml per °C by sample $\frac{d(f - e)}{a(c - f)}$	0.66	1	0.66	0.46	0.67	cal/ml °C
Heat loss per g of solid $\frac{d(f - e)}{b}$	5.1	9.5	3.2	9	6.4	cal/g
Heat loss per g per °C of sample $\frac{d(f - e)}{b(c - f)}$	0.08	0.15	0.05	0.16	0.12	cal/g°C

Note that these values are specific heats and may be compared with standard values. Also, note that

$$\underset{\text{(specific heat)}}{\frac{\text{cal}}{\cancel{g}{}^\circ\text{C}}} \times \underset{\text{(density)}}{\frac{\cancel{g}}{\text{ml}}} = \frac{\text{cal (heat lost)}}{\text{ml}^\circ\text{C}}.$$

Questions:

1. How do the heat capacities of other substances compare with the heat capacity of water?

All other substances available to the student have much lower heat capacities.

2. Does the heat capacity of a substance seem to be related to its density?

Yes, although it may not be too evident to the student, since it is an inverse relationship.

3. Does the state of matter influence its ability to hold heat?

Water as a liquid seems to have much more heat capacity than the solids used in this experiment. Caution students against over-generalization.

4. Relate the idea of heat capacity to your theories for the structure of matter and the nature of heat.

If heat is particle motion, then what sorts of motion make water absorb so much more heat than other substances? If heat is a fluid, why does the amount associated with particles vary with the kind of particle? Actual student response on this item will probably be limited. The variation is related to interparticle forces and the modes of vibration that particles can have.

Conclusions and suggestions for further investigations:

Based on the materials used, water is shown to have an unusual capacity to absorb heat. This is an instance where students may find the results in definite disagreement with what they thought was the best hypothesis. It is a demonstration of the need to experiment to check what reasoning and common sense tell you.

Further investigation: Find heat capacities for other substances either through experiment or through library research.

Reporter ______________________ Date ______________ 6 1 page 127

Team Members ______________________________________

Problem: Does heating cause a loss in mass for a sample of gas?

Hypotheses:

(1) Heating causes a loss of mass in a sample of gas.
(2) Heating does not cause a loss of mass in a sample of gas.

Ask students to qualify their hypotheses.

Attack: Place two sealed flasks on opposite arms of a two-pan balance and adjust the balance so that static equilibrium exists. Heat one of the flasks with a heat lamp to see if this upsets the equilibrium.

CAUTION: Do not heat the flask excessively; the stopper could be blown out.

Materials:

two-pan balance
2 flasks
2 one-hole stoppers
2 thermometers
heat lamp

Observations:

The results are variable and inconclusive. Students should take periodic readings of the distance above the table of one flask and relate distance to temperature at the time of each reading. Heat sources often produce convection currents which can disturb the heated flask. Lack of awareness of this factor can lead to mistaken interpretations of the results. Suggest that students vary the technique by first heating the flask while it is on the balance, then heating the flask at a different location and placing the hot flask on the balance.

Questions:

1. Are your observations in agreement with those of your classmates?

Different techniques of applying heat will produce different amounts of convection currents, so that observations will vary.

2. If heating a gas sample changes its mass, what do you think would happen if you cooled the gas sample? Test your prediction.

It should produce the opposite result. If heating causes a loss in mass, then cooling should cause a gain in mass.

3. If heat does show itself by reducing the observable mass of a gas sample, would you expect the same effect with solids and liquids?

Yes. Some students might argue that heating the glass of the flask caused the observed results.

4. Why is it important to use sealed flasks?

To keep the quantity of matter constant during the experiment.

Conclusions and suggestions for further investigations:

A direct conclusion based on this experiment is very unlikely. If the experiment does suggest the idea of negative mass, the implications of it should be explored along with the implications of heat having mass. The latter suggests that heat is matter. Does it have to be?

Further investigations: (1) Make an experimental effort to refine this experiment. (2) Discuss implications of various assumptions about the nature of heat. (3) Make a library search for what others have thought about heat.

Reporter ______________________ Date ______________ 6 2 page 128

Team Members ______________________________________

Problem: What is the relationship between the volume and the temperature of a sample of gas?

Hypotheses:

(1) The volume of gases is increased by heat.
(2) Gases are unaffected by heat.

Attack: Seal one end of the glass tubing by heating it. While the tube is still warm, dip the open end into a droplet of mercury so that a small bit of the mercury can enter the tube and become a free moving piston.

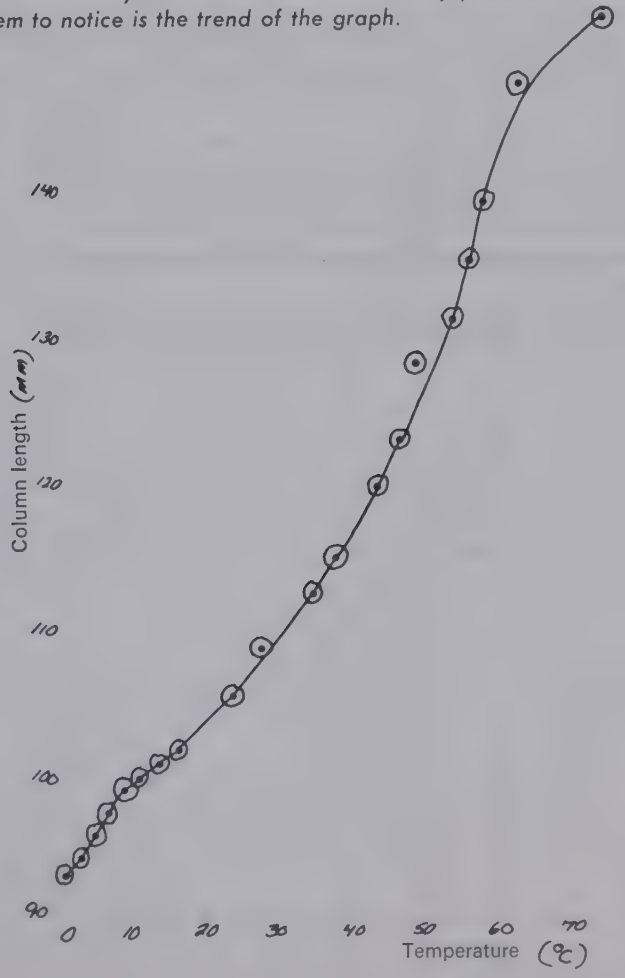
Bind the tube, a metric scale, and a thermometer together and insert them into ice water. Then gradually warm them from near 0°C to about 60°C.

Materials:

glass tubing, 20 cm by 2 mm
(inside diameter)
thermometer
20-by-150-mm test tube
beaker
heat source
metric scale

Observations: (Record the length of the gas sample and the temperature every few degrees of temperature change.) *Suggest to students that they do not need to include every point in the curve. What is important for them to notice is the trend of the graph.*

Temperature	Column length
0°C	93mm
3	94
4	96
6	97
9	99
13	101
16	102
23	105
27	108
33	112
38	115
43	120
46	123
49	127
52	131
55	135
58	139
62	147
65	152
70	162



Questions:

1. How much did the volume change between 10°C and 20°C? between 20°C and 30°C? between 50°C and 60°C?

10°C–20°C: 4 mm
20°C–30°C: 6 mm
50°C–60°C: 13 mm

2. On a separate sheet of graph paper plot your results using the Kelvin scale instead of the Celsius scale. Extend the line of your plot until it intersects the temperature axis. What is the significance of this point of intersection?

Don't be surprised if the students' extrapolation does not resemble the ideal represented by the graph on page 130 of the text.

3. What would you predict as a result if a gas other than air were used in the tube?

The most likely prediction is that the results would be similar.

4. Why do you think gases change volume so much more than solids and liquids?

Under the caloric theory, the heat pushes the particles apart. For gases there is enough heat to keep the particles widely spaced. The result is great sensitivity to heat.

Under the idea of particle motion, the particles of a gas are far apart and free to move unrestrictedly. Motion causes them to fill space. Heat causes higher velocity and still greater tendency to fill space.

Conclusions and suggestions for further investigations:

Gases expand as temperature rises and they contract as the temperature is lowered. Because of continued contraction as the temperature is lowered, it is possible that gases could reach a point of zero volume. Any predictions of absolute zero from students' data will not fall at the accepted absolute zero except by accident. However, the general significance of absolute zero becomes evident as an experimental possibility.

Further investigations: (1) Study the expansion and contraction of gases other than air. (2) Try to obtain and study a sample of perfectly dry air.

Reporter ______________________ Date ______________ 6 3 page 132

Team Members ____________________________________

Problem: What can be learned about gases by studying the diffusion of one gas into another?

Attack: Allow a detectable gas or gases to diffuse down a long glass tube. Keep a record of the time needed for the gas or gases to move an observable distance in the tube. If possible vary the temperature and position of the tube.

Hypotheses:

(1) Gases diffuse at the same rate regardless of kind and temperature.
(2) Each gas has its own rate of diffusion at a particular temperature.

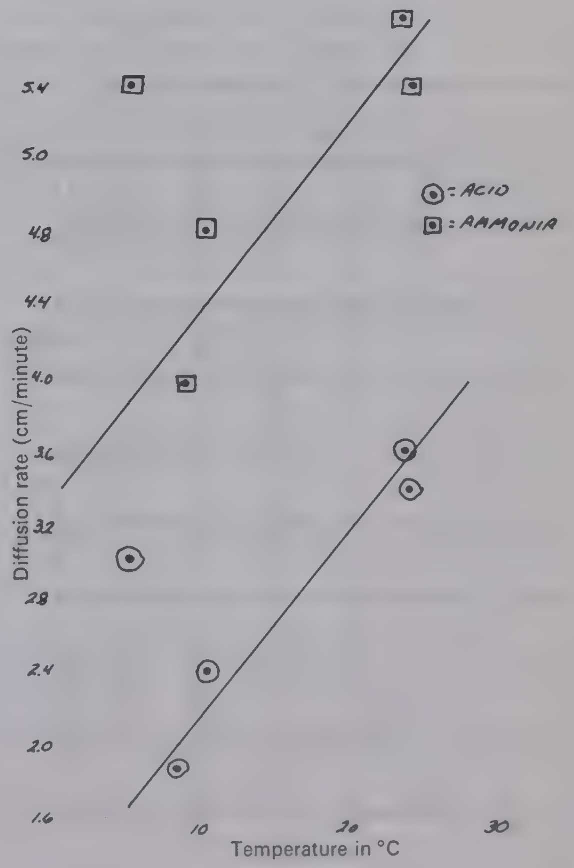
Materials:

glass tube, 50 or more cm long, 2 cm in diameter
2 stoppers to fit the test tube
2 droppers
thermometer
small quantities of hydrochloric acid and ammonia

Observations:

This sample of student data will provide an idea of potential variation in data. Getting a reasonably accurate reading of the actual temperatures of the gases is difficult.

Trial	1	2	3	4	5	6
Temperature (°C)	24	24	8	10	5	5
Distance traveled by ammonia (cm)	58	62	45	59	70	68
Distance traveled by acid (cm)	34	39	23	29	37	23
(sec) Time required (min)	600 10	630 10.5	660 11	720 12	715 12	410 6.9
Tube position	HORIZONTAL					
Percent of total distance traveled by the acid	36	38	33	32	34	25
Percent of total distance traveled by ammonia	64	62	67	68	66	75
Rate for the acid (cm/min)	3.4	3.6	1.8	2.4	3.0	3.0
Rate for ammonia (cm/min)	5.8	5.4	4.0	4.8	5.4	6.0



Questions:

1. Is diffusion rate related to temperature?

Yes, it is, although students may have difficulty collecting enough data to give a precise picture of the relationship.

2. Does the position of the tube affect the diffusion rate?

Gravity will affect the rate of diffusion of a heavy gas up or down a vertical tube.

3. Do the two gases travel down the tube the same distance in the same period of time?

No, the ammonia travels about twice as fast as the hydrogen chloride.

4. Does a change in temperature cause a change in the way the rates for the two gases compare?

No, the ammonia travels twice as fast at all temperatures.

5. Can a caloric fluid theory effectively explain the diffusion of gases?

No, it does not explain why the gases, at the same temperature, still tend to scatter and mix.

Conclusions and suggestions for further investigations:

The two gases, ammonia and hydrogen chloride, do not diffuse at the same rate at the same temperature. The ammonia generally went about twice as far in the same time as the hydrogen chloride. Vertical placement of the tube affects the relative rate of diffusion, since gravity is added or subtracted from the diffusion rate.

Further investigations: (1) Study the diffusion of other gases, making special effort to detect the arrival of the gases (see supplementary experiment D in Chapter 6, page 140 of the text). (2) Refine this experiment by controlling and measuring the temperature.

Reporter ____________________ Date ____________________ 6 4 page 134

Team Members ____

Problem: What further evidence, in addition to diffusion, can be collected that indicates motion of gas particles?

Hypotheses:

The invisible gas particles can cause motion in particles that are large enough to be seen under a microscope.

Attack: Obtain or build a small chamber for containing smoke particles. The chamber should be lighted from the side so that light will reflect from the particles into the objective lens of the microscope used for viewing.

Materials:

- chamber
- microscope
- strong light source
- magnifier
- matches or other source of smoke

Observations:

The smoke particles jitter or vibrate in place, as well as move across the field of view and either up or down out of the focal plane.

Questions:

1. Compare your observations in this experiment to those of Experiment 6–3.

Both the diffusion seen in Experiment 6–3 and the vibration observed in this experiment indicate that particles of gases are moving.

2. How do the smoke particles compare in size to the gas particles?

It can be inferred that the smoke particles are thousands of times larger, since the motion induced in them is so slight.

Conclusions and suggestions for further investigations:

The erratic motion of smoke particles can be interpreted as indirect evidence for the motion of gas particles.

Further investigations: (1) Observe the trail of ionized particles in a cloud chamber. (2) Undertake library research into accounts of experiments relating to velocities of particles.

Supplementary
Experiment for
Chapter 6
(see p. 138)

Reporter ______________________ Date ______________

Team Members ______________________________________

Problem: How does the diffusion rate of carbon dioxide compare with that of other gases?

This is an optional experiment which can be done as a demonstration or as a further investigation for Experiment 6–3.

Hypotheses:

(1) Carbon dioxide will diffuse more slowly than ammonia or hydrogen chloride.
(2) It will diffuse more rapidly.
(3) It will diffuse at the same rate.

Attack: Place a source of carbon dioxide at the bottom of a beaker or a tall cylinder. (Dry ice is best, but marble chips in hydrochloric acid may be used.) Use a glowing splint to trace the arrival of the carbon dioxide at the mouth of the container. Keep a record of the time needed for the gas to travel up the container.

Limewater might be used as an alternative way of detecting the carbon dioxide.

Materials:

glass tube, 50 or more cm long, 2 cm in diameter
source of carbon dioxide
wooden splints

Observations:

The carbon dioxide diffuses upward quite slowly, downward quite rapidly, and along a horizontal tube more slowly than hydrogen chloride or ammonia.

Questions:

1. Does the vertical position of the tube affect the results?

Experience with Experiment 6–3 should indicate that it does affect results.

2. If dry ice is used, can you take the effect of temperature into account?

The low temperature of the dry ice slows the rate of diffusion.

3. Does this experiment give you a basis for comparing the particle weight of hydrochloric acid gas, ammonia gas, and carbon dioxide gas?

Carbon dioxide may diffuse more slowly than hydrogen chloride and ammonia because its particles are heavier. Diffusion is proportional to particle speed, and if two particles have the same energy of motion, the one with the greater mass will have the slower speed.

Conclusions and suggestions for further investigations:

If diffusion is related to the mass of the particles, then carbon dioxide particles are greatest, hydrogen chloride next, and ammonia lowest in mass.

Further investigation: Study the diffusions of other gases, such as helium, hydrogen, oxygen, and nitrogen.

Reporter ______________________ Date ____________________ 7 1 page 146

Team Members ____

Problem: What factors other than heat affect the evaporation rate of a liquid?

Hypotheses:

(1) The amount of surface area exposed to the air will affect the evaporation rate.
(2) Movement of air across the surface of a liquid affects the rate of evaporation.

Attack: Place equal amounts of water in the test tube and beaker. Set them aside in a quiet place and let the water evaporate. Put equal amounts of water in two more beakers. Blow air over one with a fan and let the other sit undisturbed. Observe the evaporation rate in all four containers.

Materials:

20-by-150-mm test tube
3 250-ml beakers
fan or other source of air current
test tube rack

Observations:

The greater the surface area, the faster water evaporates. Air blown across a water surface increases the rate of evaporation.

Questions:

1. Is there a process that is the opposite of evaporation? If so, can its rate be changed and would such changes affect evaporation?

Yes, it is condensation. If vapor collects over a liquid surface, some of it will condense back into the liquid. Such condensation can be rapid enough to equal evaporation.

2. Does this experiment contain evidence favoring a particle motion theory?

It certainly suggests motion. It can be inferred to be particle motion.

Conclusions and suggestions for further investigations:

Surface area can be viewed as an escape window—the larger the window, the more particles that will escape. Air motion sweeps the particles away so they have no opportunity to condense and partially neutralize the evaporation.

Further investigation: Study other factors that affect evaporation. For example, do solutions evaporate as rapidly as the solvent by itself?

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Reporter ____________________ Date ____________

Team Members ______________________________

Problem: Does the boiling temperature depend upon the air pressure above a liquid?

It is advisable to do this experiment as a demonstration.

Hypotheses:

If the boiling temperature does depend on the pressure above a liquid like water, then change in that pressure will change the boiling point.

Attack: Boil the water in an open flask for a minute or so to allow it to fill with water vapor. Remove the heat source and seal the flask with a stopper that has a thermometer mounted in it. Invert the flask and run cold water over it.

CAUTION: Handle the flask very carefully. If scratched or bumped it can *implode* and then explode.

Materials:

250-ml round bottom flask
one-hole stopper to fit flask
thermometer
ringstand, ring, and asbestos pad
test tube clamp
source of heat
toweling to use as a hot pad

Observations:

Cooling increases the bubbling in the water in the flask. Water condenses on the inner walls of the flask.

Questions:

1. Does equilibrium exist at any time inside the flask?

Yes, when boiling stops, equilibrium between evaporation and condensation seems to exist.

2. Does this experiment supply evidence for particle motion or for caloric fluid?

Either. Caloric fluid is drawn out of the vapor by cooling, so particles condense. Particles are slowed enough so that they cluster into droplets and fall into the liquid.

Conclusions and suggestions for further investigations:

The boiling temperature of water, and probably of many other liquids, is changed by changing air pressure. Cooling causes a condensation of water vapor, and thus is a way to reduce the pressure in an atmosphere that is almost 100 percent water vapor. As the cooling occurs, the upset in equilibrium causes boiling.

Further investigation: Observe directly the effect of reduced pressure on boiling temperature, if an aspirator is available.

Reporter ____________________ Date ____________________ 7 3 page 152

Team Members ____

Problem: Is it possible to observe evidence of particle motion in liquids similar to that observed for gases?

Hypotheses:

If the particles of liquids bombard particles visible under the microscope with enough force, then motion of the larger particles will be observable.

Attack: Observe a drop of very dilute milk under a microscope for motion in the visible milk particles.

Materials:

- microscope
- glass slide
- cover slip
- drop of diluted milk
- strong light source

Observations:

The vibration of particles is evident.

Questions:

1. What similarities and differences did you observe between the particle motion in the milk drop and the particle motion in the gas chamber used in Experiment 6–4?

None. The motion seems to be the same.

2. Use your observations in this experiment to explain why some substances remain suspended in a liquid and why others settle out.

Small particles keep colliding with larger particles. This keeps them suspended if their surface area is large enough for them to receive many collisions per second. When settling occurs, it is due to a relatively large gravitational force acting on particles of relatively high mass and small surface area.

Conclusions and suggestions for further investigations:

The vibrating particle motion is evident in liquids. It may be one of the reasons why some particles remain suspended and others settle out.

Further investigation: Check drops from suspensions such as those made in Experiment 3–2 to see if particle motion is evident.

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4
page 152

Reporter ______________________ Date ______________

Team Members ______________________________________

Problem: What effect does temperature have on the rate of diffusion of a solute into a solvent?

Hypotheses:

Since diffusion in gases was affected by temperature, the diffusion in liquids should be affected in a similar way.

Attack: Drop one crystal each of potassium permanganate into the bottom of two tall containers, one with hot water and the other with cold water. Observe the rate of diffusion into the water in each container.

See page 152 of teachers' edition of text for additions to "Attack" for this experiment.

Materials:
4 20-by-150-mm test tubes
2 one-hole stoppers to fit test tubes
2 droppers
2 solid stoppers to fit test tubes
small pieces of double-sticky tape
crystals of potassium permanganate
bottle of ink

Observations:

The diffusion rate is greater in hot than in cold water. The potassium permanganate dissolves more rapidly in hot than in cold water.

Questions:

1. Why would high temperatures produce more rapid diffusion than low temperatures?

(1) There is more caloric fluid on the solute particles; it repels the particles and drives them apart.
(2) Increased temperature produces an increase in motion that drives particles apart.

2. Is this experiment consistent with the particle motion theory?

Yes, since the increased motion associated with higher temperatures would explain the increase in rate of diffusion with temperature.

Conclusions and suggestions for further investigations:

Increases in temperature cause an increase in the rate of diffusion.

Further investigation: Refine the experiment by following the cues suggested by the illustration on page 153 of the text and by the explanation in the teachers' edition.

Reporter ______________________ Date ______________

Team Members ______________________________

Problem: What ability do we have to sense radiation directly without the aid of instruments or our eyes?

Hypotheses:

We are quite sensitive to various kinds of radiation and can feel them on our skin. Different places on our bodies have different sensitivities.

Attack: While blindfolded, attempt to detect sources of radiation. Let a classmate bring a variety of sources of radiation near your hand or your face to see if you can tell whether it is there.

CAUTION: It is best for you to stand or sit still while your partner brings the items to be tested near you.

Materials:

- sources of radiant energy: incandescent and fluorescent light bulbs, a hot iron, a can of hot water, a can of ice water, direct sunlight, and a candle
- cloth for the blindfold
- meter stick

Observations: Record the distance between radiator and sensing point when detection occurs.

Point of sensitivity	Source of radiation						
	Incandescent lamp	Fluorescent lamp	Iron	Candle flame	Hot water	Cold water	Sunlight
Forehead	5cm		4cm	5cm	< 1cm	< 1cm	10" m
Lips	5cm		6cm	5cm	<1cm	< 1cm	10" m
Cheek	10cm		6cm	4cm	<1cm	<1cm	10" m
Palm of hand	10cm		—	1cm	< 1cm	—	10" m
Back of hand	8cm		—	2cm	< 1cm	—	10" m
Inner wrist	15cm		1.5cm	3cm	< 1cm	—	10" m

Questions:

1. Which areas of the body are best equipped to detect radiation?

The face is most often reported as best, although its sensitivity seems to vary with nature of source.

2. Are you equipped to be a good radiation detector?

Yes, we can detect radiation.

3. Are you a source of radiation?

Yes, the sensing of the can of ice water is due to increase in radiation loss from your body to the cold can.

Conclusions and suggestions for further investigations:

Our skin does contain sensors for radiation. The sensitivity is not uniform; it changes with location on our body. The sensitivity seems to change with the source and intensity of radiation.

Further investigation: Check other radiation sources, such as an infrared lamp and a hot plate.

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Reporter ______________________ Date ______________

Team Members ______________________________________

Problem: Is it possible to construct a simple, easy-to-build device that is very sensitive to radiation?

Hypotheses:

It is possible to build a device for detecting radiation. (A hypothesis is somewhat artificial in this instance, since this is a construction activity.)

Attack: Assemble an apparatus that traps two quantities of air connected by a tube of liquid. The two air quantities should be separated and shielded so that the potential radiation source can be brought near one without affecting the other.

Materials:

U-shaped glass tubing, 6 mm in diameter
2 small test tubes
2 one-hole stoppers to fit test tubes
large corrugated cardboard box
heat shield (such as a piece of corrugated cardboard)

Observations:

More than one effort may be necessary to prepare a U-tube so that the arms are in the same plane. Modeling clay can be added to the equipment list and used as feet to hold the tube and glass assembly upright. A bit of food coloring in the water will make it more visible.

Questions:

1. Would the size of the test tubes influence the sensitivity of a differential air thermometer?

The smaller the tube receiving the radiation, the more pronounced the change in air pressure should be. Thus a smaller tube should be more sensitive.

2. Is it essential for the thermometer to have two trapped quantities of air or could one end be open?

No, one end open would detect radiation but would not compare two sources simultaneously.

Conclusions and suggestions for further investigations:

The conclusion is limited to a statement of success about the construction of the differential air thermometer.

Reporter ______________________ Date ______________

Team Members ______________________________________

Problem: Does the temperature of an object affect its radiation rate?

Hypotheses:

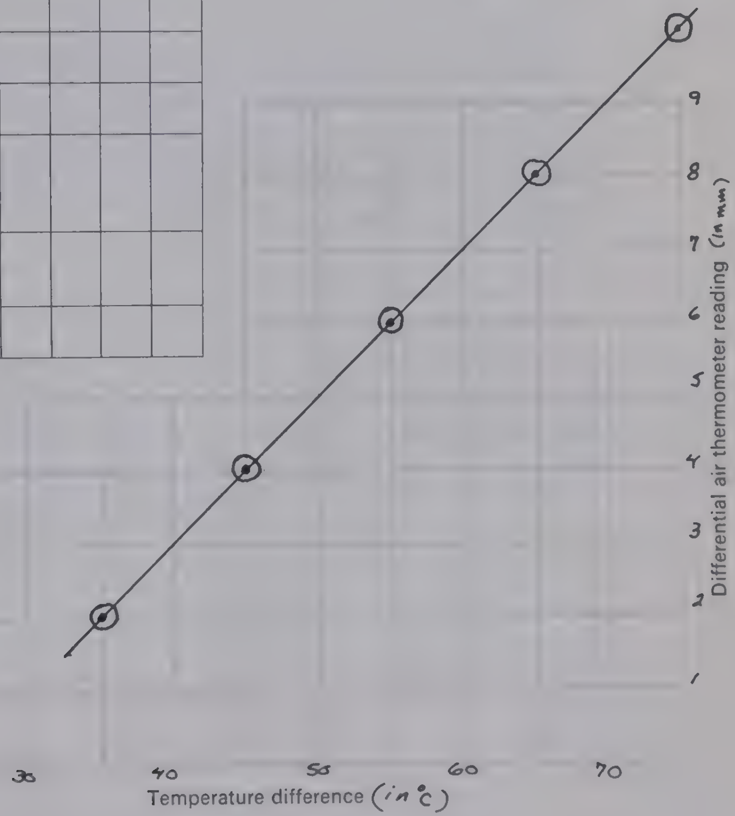
Radiation rate should be greater from hot objects than cold objects. The differential air thermometer is sensitive enough to detect small differences in amount of radiation.

Attack: Use the differential air thermometer as a radiation detector in a study of radiation from containers of hot and cold water.

Materials:
differential air thermometer
2 similar containers
2 thermometers
candle
aluminum foil
metric scale
supports for containers

Observations: *The changes in the differential air thermometer are very slow and small.*

	Trial	1	2	3	4	5	6	7	8	9	10
°C	Hot water temp.	80	70	60	50	40					
°C	Cold water temp.	5	5	5	5	5					
°C	Temp. difference	75	65	55	45	35					
mm	Thermometer scale reading	10	8	6	4	2					
mm	Container distance from thermometer bulb	2	4	6	8	10					
°C	Temp. of water in container	80	80	80	80	80					
mm	Thermometer scale reading	10	8	6	4	2					



Questions:

1. Are any materials both good radiators and good insulators?

None. Since insulators tend to hold heat, the radiation from a good insulator would be quite low.

2. Is there any evidence that cold objects radiate heat?

We usually think of hot objects as being above room temperature. However, an object at +10°C should radiate more than an object at −10°C.

3. What effect does distance have on the radiation that reaches the bulb of the differential air thermometer?

Increasing distance reduces radiation. The inverse square relationship should apply, but experimental results may not show it.

4. Does either the particle motion theory or the caloric fluid theory provide a means for explaining radiation?

No, radiation is not explained by either theory.

Conclusions and suggestions for further investigations:

If hot objects and colder objects are equidistant from the bulb of a differential air thermometer, the hot objects cause more expansion in the air chamber. This result suggests that they radiate more heat than the colder object.

Further investigations: (1) Try to get actual data as an answer to question 2. (2) Try to test more carefully the applicability of the inverse square law to the radiations from hot objects. (3) Compare the radiation from a candle with some of the other objects used in Experiment 8–1.

Reporter ______________________ Date ______________ 8 4 page 164

Team Members ______________________________________

Problem: To test the effects of radiation conditions on plants.

Hypotheses:

(1) Plants receiving light will develop green leaves.
(2) Plants cut off from light may grow a while but will not become green.
(3) Plants simply won't grow without light.

Attack: Plant pieces of potato under a variety of radiation conditions. Keep other conditions as constant as possible. Observe the seedlings over a period of several weeks to see if there are variations in coloration and rate of growth.

Materials:

3 beakers or plastic cups
2 large cans, one with a transparent cover
2 glass jars, quart-sized or larger
potato
large two-hole stopper to fit glass jar
aquarium

Observations:

(Temperature within the containers was consistently higher than outside air but relatively uniform between containers.)

First day:	*Small sprouts appear on each piece.*
Second day:	*No change can be seen. Water is forming on jar sides.*
Third day:	*All sprouts show some growth; no differences can be seen.*
Fourth day:	*Shoots on potato in jar seem to be changing to greenish color. Other shoots are not coloring but are growing longer.*
Seventh day:	*Longest shoot on potato under the can is more than 10 cm long. It is still milky white without leaves. Shoots under this can seem to be wandering. White shoots in plastic-lidded can are growing upward. In glass jar, shoot is about 6 cm long, and leaves seem to be forming. Another piece was started in a jar under water.*
Tenth day:	*Shoots under the can are still white without leaves and are now bending down after touching can. Shoots in plastic-lidded can have reached lid at can edge. They are bowed and seem to be very pale yellow-green without leaves. In the glass jar the shoots are pointing a little toward the light, and a second set of green leaves is forming. Potato in jar under water is still the same.*
Fourteenth day:	*Shoots in the two cans are still pale and are getting longer without leaves. The potato part is shriveling. Sample under glass continues to grow normally. Sample under water is about the same as that without water.*

Questions:

1. What are the apparent differences between the plant that received light and those that did not?

In the light, the shoots are shorter, and green leaves have formed. Where light is absent, the shoots are long and white.

2. Could plants survive with heat radiation only?

Probably not. This is the condition under the can, and the plant does not develop green leaves.

3. Could plants survive with light radiation only?

Probably. If we can assume that the water cuts off heat radiation, then the growth of the plant in the jar in the aquarium indicates that plants are not dependent on heat radiation, but will survive with only light radiation.

4. How does this experiment show that radiation interacts with matter and possibly becomes a part of matter?

Irradiated plants form green leaves and show a form of growth not evident in the plants that do not receive visible radiation.

Conclusions and suggestions for further investigations:

The amount and the kind of radiation seem to influence the growth of these plants. Visible light seems to be necessary to produce green leaves. Shoots that develop in the dark seem to grow longer.

Further investigation: Raise several "gardens" in containers under water and control the temperature of the water surrounding the jar. See if the growth rate is influenced by water temperature.

Reporter ______________________ Date ______________________ 8 5 page 165

Team Members ____

Problem: Under what light conditions do algae grow in an aquarium?

Hypotheses:

(1) Plants grow well in light of any color.
(2) Plants grow well only in light of certain colors.

Attack: Cover all but one side of your aquarium with opaque paper or paint. On the remaining side put strips of colored cellophane so that the type of light entering the aquarium can be controlled.

Materials:

aquarium (could be a quart jar)
cellophane, several colors
opaque paper or paint
algae to seed the aquarium

Observations:

Algae will grow in the areas where blue light and red light are transmitted into the aquarium. Growth will be minimal behind cellophane of other colors, and absent behind the opaqued sides.

Put the cellophane on the aquarium in vertical strips so that the depth of the water is not one of the variables. This experiment will produce better, more positive results if left for a long period of time. As an alternate setup, use a separate, small container for each color tested.

Questions:

1. What is the most obvious condition that causes variation in the growth of the algae?

Light is the variable that causes the most change in the growth rate.

2. What conditions are necessary for algae to grow?

Water and light. A minimum temperature level and a supply of carbon dioxide are factors that students can tentatively identify.

3. What color light allows the algae to grow the best?

Red light and blue light seem to be most useful to the algae.

4. Does the depth of the water influence the growth of the algae?

This experiment does not give information about this question, but students might realize that depth affects the supply of carbon dioxide.

Conclusions and suggestions for further investigations:

Not all of the colors in white light are needed for algae to grow and thrive. Blue light and red light seem to be the ones that are useful.

Further investigations: (1) Study the effects of water depth and carbon dioxide supply. (2) See if infrared (heat) radiation is utilized by the algae.

Reporter ______________________ Date ______________

Team Members ______________________________________

Problem: Can radiation be converted to mechanical motion?

Hypotheses:

Yes, the radiometer will move when a light beam shines on its vanes. If the light source is moved away, the rate of rotation will be slower.

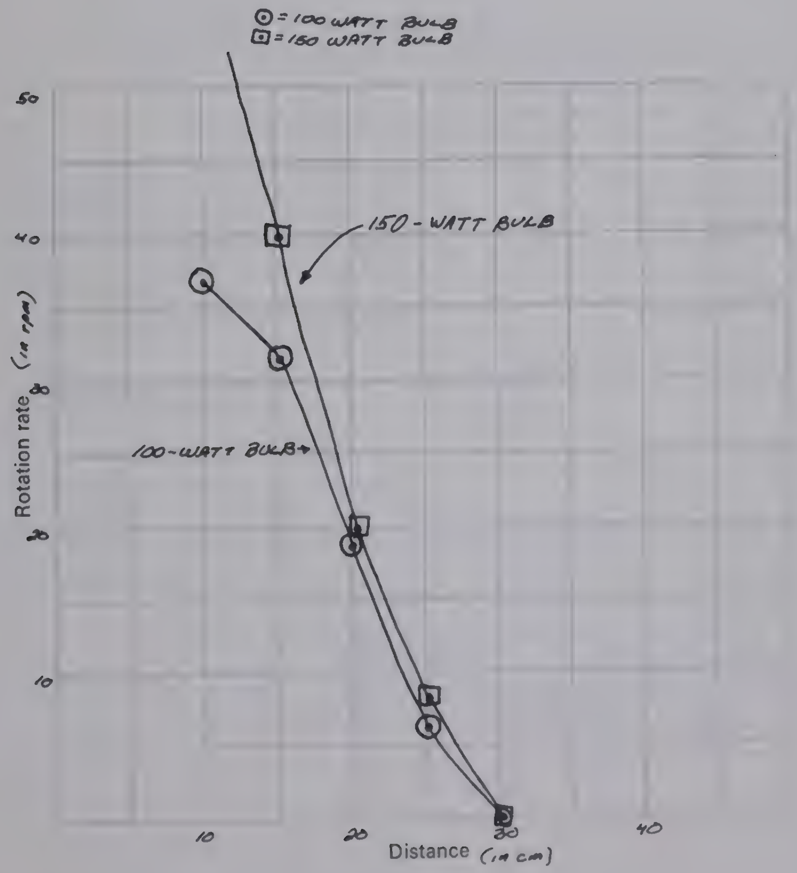
Attack: A radiometer should be sensitive enough to show a mechanical response to radiation. Bring one near a light source and observe its response. Note the distance and the effect of the intensity of the source on the action of the radiometer.

Materials:

radiometer
electric lamp
light bulbs of a variety of wattages
reflectors for the lamp
meter stick

Observations:

At very low rotations per minute (rpm) the radiometer seemed to be subject to some friction and did not give a consistent response to the light.



100-WATT BULB

cm	rpm
30	0
25	6
20	18
15	32
10	36
5	TOO FAST TO COUNT

150-WATT BULB

cm	rpm
30	0
25	8
20	20
15	40
10	60
5	TOO FAST TO COUNT

Questions:

1. Are your hypotheses for this experiment confirmed by the experiment? Explain.

Yes, the radiometer turns. As the light is moved away, the rate of rotation slows.

2. Explain the relation between rotation rate of the radiometer and distance from a light source.

Most simply, the closer the constant source of light, the faster the radiometer turns.

3. What two factors seem to affect the rate of rotation of the radiometer?

Distance from the light source and the intensity of the source.

4. Is the radiometer sensitive to heat radiations as well as light radiations?

It responds to an infrared lamp.

Conclusions and suggestions for further investigations:

Heat can be converted to the motion of a radiometer. The amount of motion depends on the intensity of the radiation source and on how close the source is to the radiometer. The closer it is, the more motion there is.

Further investigation: Try to find other conversions of radiant energy.

Reporter ______________________ Date ______________ 9 1 page 173

Team Members ______________________________________

Problem: What work is done in lifting an object?

Hypotheses:

The amount of work depends on the mass of the object and the distance it is moved.

Attack: Suspend a 1.0-kilogram mass from a spring balance, then lift it through measured distances.

Materials:

1.0-kilogram mass
spring balance
meter stick

Observations:

The reading on the scale of the spring balance seems to be the weight of the object. It changes only when the object is moved very quickly. If the object is moved smoothly and evenly, then the reading is for the weight of the object.

Questions:

1. How many different combinations of mass and distance could be used in doing 2.0 kgf-m of work?

An infinite number of combinations.

2. What work is done if 150 kg are lifted through a distance of 5 meters?

Force × distance = work
150 kgf × 5 meters = 750 kgfm

3. What energy is released as a 150-kg mass falls back the 5 meters to its original position?

750 kgfm, the same as the work required to lift it through the 5 meters.

Conclusions and suggestions for further investigations:

Work is done against gravity when an object is lifted. If the object is lifted very slowly, the force with which you pull it just balances the force of gravity on it. The work you do is then the force of gravity times the distance you lifted the object.

Further investigation: Try to use the energy of falling objects to do useful work.

Reporter ______________________ Date ______________ 9 2 page 176

Team Members ______________________________________

Problem: What is happening to the energy in a system as a pendulum swings back and forth?

Hypotheses:

The energy stays in the system but changes from energy of motion to energy of position.

Attack: Set up a simple pendulum and set it in motion. Observe its action carefully. Insert an obstruction so that the length of string that is moving is changed.

Materials:

one-hole rubber stopper
length of string
pencil
chalkboard or other surface on which to mark the motion of the pendulum
piece of chalk

Observations: A sketch would be a good way to record your observations. Label it clearly.

The pendulum rises to the same height on each side of its swing. At the bottom of its swing it is going quite fast, then gradually slows to a stop, and then starts its return swing.

The pendulum rises to the same height regardless of whether the swing is interrupted or not. The only change that the obstruction makes is to change the path or arc taken by the weight used on the pendulum.

Questions:

1. If the stopper has a mass of 0.1 kg, how much potential energy does it have at the highest point in its swing as compared with the lowest point in its swing?

Potential energy = force × distance = 0.1 kgf × height lifted

2. What effect does the insertion of an obstruction have on the rise and fall of the stopper?

None, except to change the path of the weight.

3. Can you account for the energy in the system at all stages of the cycle?

Yes, it is either entirely position energy, or motion energy, or a mixture of the two. The total remains constant.

4. Does this experiment support the idea that energy is conserved?

In the first few swings it does, but then the gradual drop in height becomes evident. There is an energy leakage (friction) that needs explanation.

Conclusions and suggestions for further investigations:

A swinging pendulum is an energy system in which kinetic energy and potential energy are constantly converted from one form to the other. If an ideal pendulum, free of friction, could be made, the total for the energy in the system would be constant.

Further investigations: (1) Find or design other systems in which potential energy and kinetic energy are converted back and forth in a continuous cycle. (2) Study pendulum clocks, how they work, and how the pendulum motion is used in the clock.

Reporter ______________________ Date ______________ 9 3 page 178

Team Members ______________________________________

Problem: Can more energy or work be obtained from a lever system than is put into it?

Hypotheses:

A lever system can produce no more energy or work than is put into it.

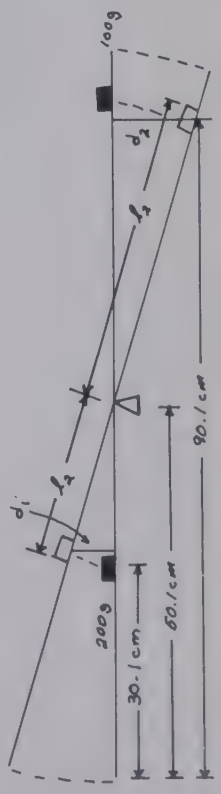
Attack: Set up a lever system and balance it with a 100-g mass on one side of the fulcrum and a 200-g mass on the other side. Move one side up or down. Measure the distance moved by each mass as they move and calculate the change in potential energy for each.

Materials:

meter stick
piece of strong thread
100-g mass
200-g mass
500-g mass

Observations: A carefully prepared sketch of the apparatus in which the masses, distances moved, and lever arm lengths are shown is the ideal form to use for recording this experiment.

	Trials					
	1	2	3	4	5	Units
Location of fulcrum	50.1	50.1				cm
Mass to left of fulcrum	200	200				g
Location of mass to left of fulcrum	30.1 28	30.1				cm
Mass to right of fulcrum	100	500				g
Location of mass to right of fulcrum	90.1	58.1				cm
Vertical distance moved by left mass d_1	8.5	8.5				cm
Lever arm of left mass ℓ_1	20.0	20.0				cm
Vertical distance moved by right mass d_2	17	3.4				cm
Lever arm of right mass ℓ_2	40.0	8.0				cm
Work done by or on left mass	1700	1700				gfm
Work done by or on right mass	1700	1700				gfm
Ratio of lever arms $\frac{\ell_1}{\ell_2}$	0.5	2.5				
Ratio of distances $\frac{d_1}{d_2}$	0.5	2.5				
Inverse ratio of masses $\frac{m_2}{m_1}$	0.5	2.5				



Questions:

1. Is energy conserved in this lever system?

Yes, as one mass moves down, the other moves up, so that the potential energy of the system is constant.

2. How do the ratios of lever arm lengths, distances, and masses compare?

$$\frac{l_1}{l_2} = \frac{d_1}{d_2} = \frac{m_2}{m_1}$$

3. How can the lever system be used to determine an unknown mass?

If the level balances, then the equation $\frac{l_1}{l_2} = \frac{m_2}{m_1}$ *can be used to solve for one unknown mass.*

4. What is the source of the force that acts and causes work to be done as the masses move in this experiment?

Slight muscle power is used to overcome friction at the fulcrum. No additional work is done on or by the system because there is no net change in potential energy (or kinetic energy).

Conclusions and suggestions for further investigations:

When a lever system is in balance, $\frac{l_1}{l_2} = \frac{d_1}{d_2} = \frac{m_2}{m_1}$. *This means that loss of potential energy by one mass is balanced by gain potential energy by the counter-balancing mass and the energy of the system is conserved.*

Further investigation: Relate levers of the kind used here to gears and wheels, and see how they are related to energy.

Reporter ______________________ Date ______________ 9 4 page 184

Team Members ____

Problem: What portion of the work put into an elastic object will it return upon release?

Hypotheses:

(1) An elastic object will return all the energy put into distorting it.
(2) Some of the energy used to distort an elastic object is lost.

Attack: Suspend a dowel between two chairs or two tables. One by one hang 100-g masses from the center of the dowel. Measure the distortion distance of the dowel after the addition of each new mass increment. Then start removing the masses one by one, reading the change in distortion of the dowel after each mass is removed. Repeat this procedure with the dowel clamped to a table edge and loaded at the other end.

Materials:

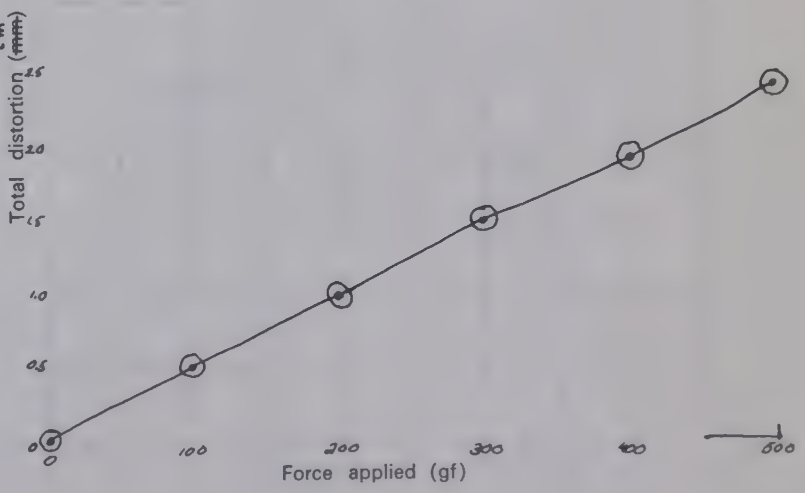
dowel, 6 mm in diameter, 60 cm long
30-cm length of string
meter stick
5 100-g masses
clamp or a stack of books for support

Observations:

Distance between supports 93 cm

Masses added		
Force applied	Scale reading	Total distortion (cm)
0 gf	76.0	0.0
100 gf	75.5	0.5
200 gf	75.0	1.0
300 gf	74.5	1.5
400 gf	74.1	1.9
500 gf	73.6	2.4

Masses removed		
Force applied	Scale reading	Total distortion (cm)
500 gf	73.6	2.4
400 gf	74.1	1.9
300 gf	74.5	1.5
200 gf	75.1	0.9
100 gf	75.5	0.5
0 gf	76.0	0.0



Questions:

1. What explanation can you offer for the distortion differences between addition and removal of masses from the dowel?

In some cases there will be no differences to explain. If the rod is very heavily loaded, then internal friction may cause a loss.

2. How elastic is a wooden dowel?

It is quite elastic, in the sense of having the ability to return to its original shape.

3. Could a flexible wooden beam be calibrated and used as a weighing device?

Yes, within limits.

4. Does this experiment support the idea of conservation of energy?

This experiment will support the idea of conservation of energy if the addition and removal curves are the same. If they are not, then there is some energy that is not accounted for.

Conclusions and suggestions for further investigations:

Some elastic objects, unless severely strained, can return all or almost all of the energy stored in their distortion.

Further investigations: (1) Test the limit of the dowel's capacity to be loaded and still return to its original form. (2) Test the elastic properties of objects other than a wooden dowel.

Reporter ____________________ Date ____________________ 9 5 page 186

Team Members ____________________

Problem: Is a rubber band more elastic than a wooden dowel?

Or, will a rubber band return to its original condition after distortion?

Hypotheses:

(1) The rubber band will return all of its distortion energy.
(2) A rubber band will not return all of its distortion energy.

Attack: Gradually load a heavy duty rubber band with 100-g masses. Record the amount of distortion each time that another mass is added. Once fully loaded, remove the masses one at a time and promptly note and record the remaining distortion.

Also look for evidence of change in temperature as a rubber band is flexed and released.

Materials:

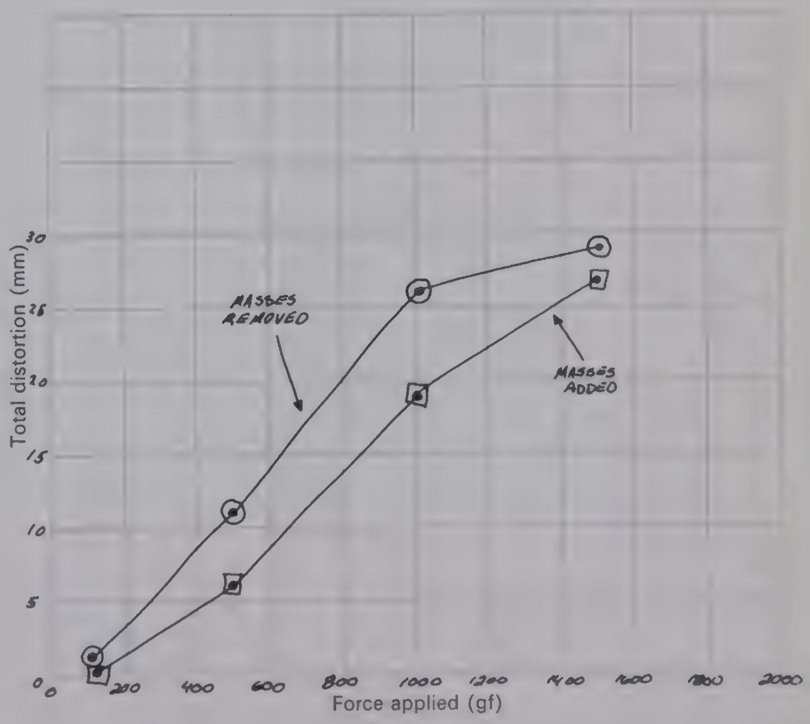
heavy-duty rubber band (3–4 mm wide)
five 100-g masses
support for the rubber band
meter stick

Observations:

Masses added		
Force applied	Scale reading	Total distortion
gf	mm	mm
100	15.5	0
500	22.2	6.7
1000	35.3	19.8
1500	43.0	27.5

Masses removed		
Force applied	Scale reading	Total distortion
gf	mm	mm
1500	44.1	28.6
1000	41.4	25.9
500	27.3	11.8
100	16.7	1.2

THE RUBBER BAND FEELS HOTTER WHEN IT IS FLEXED THAN WHEN IT IS RELEASED.



Questions:

1. How does the elasticity of rubber in a rubber band compare with the elasticity of wood?

It is less. It does not return all the energy put into it and it does not return to its original condition.

2. Wood and rubber, as pieces of matter, can be made of particles according to one of our theories. When they are distorted, some particle motion occurs. Could this be an explanation for the difference in energy put in and energy that comes out of the rubber band and the dowel?

Yes, particle motion is heat which the rubber band or wood would tend to lose by radiation, thus losing energy from the system. Heating the rubber band should return the lost energy.

3. Would a piece of rubber become more elastic or less elastic if it were chilled or warmed?

Heating might allow particles to take up new positions more freely, with less tendency to return to the old position. Chilling should have the opposite effect.

4. From your experience with this experiment and Experiment 9–4, devise a definition for the word *elastic.*

Elastic refers to the tendency of a distorted piece to return to its original condition when the distorting force is removed.

Conclusions and suggestions for further investigations:

A rubber band is elastic but not as elastic as wood. Some of the distortion energy is lost. The band does not return to its original condition.

Further investigations: (1) Add more weight to the rubber band to see if its response is different when it is more heavily loaded. (2) Study the effect of heat and cold on the loaded rubber band.

Reporter ______________________ Date ______________ 9 6 page 190

Team Members ______________________________________

Problem: Is there a relationship between motion energy and heat?

Hypotheses:

Motion energy can be changed to heat.

Attack: Rub wood and sandpaper together. Continue until an obvious rise in temperature occurs.

Materials:

blocks of wood, 1″ by 3″ by 6″
piece of fairly coarse sandpaper
thermometer

Observations:

Both paper and wood become distinctly warmer. If this experiment is supplemented by use of power equipment, then the heat generated easily rises to the level of scorching the wood. This is a rather simple experiment. Its intent is to focus attention on the idea of converting motion of large objects to particle motion at the submicroscopic level.

Questions:

1. Can motion energy be converted to heat?

Yes, the paper and wood become warm.

2. The experiments of this chapter deal with the links connecting radiations, mechanical motion, and heat. As a result of your experience, can you accept all of these as forms of energy?

The experiments show that one form of energy can be converted to others. This is strongly suggestive that radiation, motion, and heat are all manifestations of the same thing.

3. Use the particle motion theory to describe what happens as friction produces heat.

The rubbing causes the particles of matter to move more rapidly. The motion energy of the sandpaper is transferred into motion of the particles in the wood and the sandpaper. The result is a rise in temperature.

4. Can the caloric fluid theory be used to describe the effects of friction?

Caloric fluid runs out of the hand and into the paper and wood where it produces a temperature rise. (An explanation of this kind is not very plausible and will elicit dissatisfaction from students.)

Conclusions and suggestions for further investigation:

This simple experiment is representative of the many instances in which motion, by means of frictional contact, becomes heat.

Further investigation: Study other illustrations of heat produced by friction.

10
1

Reporter ______________________ Date ______________________

Team Members ______________________

Problem: What relationship exists between the strength of a magnetic field and the distance from the pole of the magnet?

Attack: Pick up a pile of filings with one card and drop it on a piece of paper. Add a second card and pick up another pile of filings. Continue until a ten card thickness is reached.

Hypotheses:

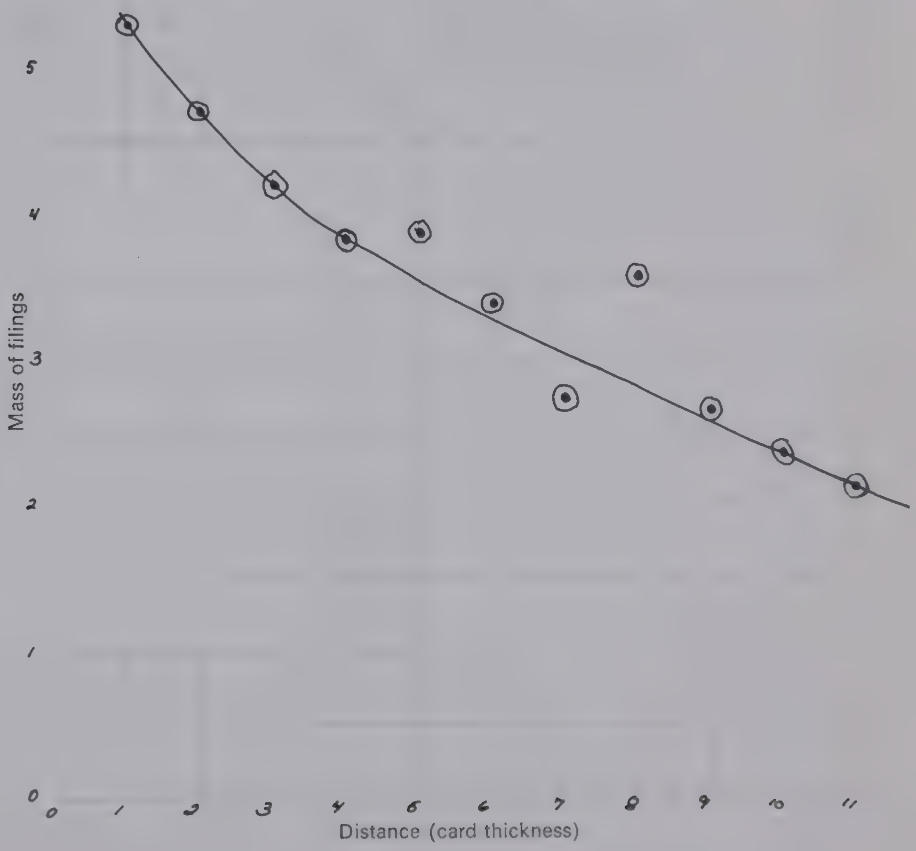
(1) The strength of the magnetic field is constant within a certain distance of the pole.
(2) The field strength diminishes as the distance from the pole increases.
(3) The field strength increases as the distance from the pole increases.

Materials:

long slender bar magnet
several file cards, 3 cm on each side
double-sticky tape
30–40 g of iron filings
2 pieces of white paper

Observations:

Trial	Distance from magnet (CARDS)	Mass of filings (g)
1	1	5.2
2	2	4.6
3	3	4.1
4	4	3.8
5	5	3.8
6	6	3.3
7	7	2.7
8	8	3.5
9	9	2.6
10	10	2.3
11	11	2.1
12	12	2.3
13	13	1.8
14	14	1.1
15	15	1.0



Questions:

1. How does the magnetic field strength change with distance?

It decreases as the distance increases.

2. Does your graph give you any clues as to the distance at which the force is zero?

No, the graph appears to curve so that it may get closer and closer to, but not touch, the zero mass line.

3. Is there any evidence that the iron filings act as magnets?

Evidence exists, but most students miss it. Place a magnet under a piece of paper and sprinkle on filings. Note that, if you reverse the polarity, the filings will stand on the opposite ends.

4. How can you relate this experiment to the other studies of energy that you have done?

Energy may be stored in magnetic materials by the position or relation of two pieces of magnetic material.

Conclusions and suggestions for further investigations:

The strength of the magnetic field, as evidenced by the quantity of filings picked up, diminishes with distance from the poles of the magnet.

Further investigations: (1) Switch poles of the magnet to see if both poles have the same strength. (2) Find whether other magnets show the same diminishing strength. (3) Try the experiment with a horseshoe-shaped magnet so that both poles are involved.

Reporter ______________________ Date ______________

Team Members ____

10
2

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Problem: What is the nature of a magnetic field?

Hypotheses:

(1) The filings will all cluster around the poles, showing a concentration of the field.
(2) The filings will scatter all around the magnet but will orient themselves in an observable way.

Attack: Place a bar magnet under a large sheet of stiff paper. Prop the paper around the magnet with pieces of cardboard. Sprinkle iron filings on the paper, then tap the table to get the filings oriented. Spray with plastic varnish to fix the filings in place.

Materials:

2 long, slender bar magnets
2 large sheets of heavy paper, 18″ by 24″
iron filings
spray can of clear varnish
can fast-drying paint

Observations:

Students will have the sheet with the anchored filings on it. They should mark the outline of the magnet.

The filings will orient themselves into a visible pattern when the table is tapped. They will also tend to move toward the nearest pole when the table is tapped. At the poles, some of the filings will stick up from the paper, distinctly indicating that the magnetic field is three-dimensional.

Questions:

1. What general quality do you find to be common to all the field patterns you have prepared?

Lines of filings seem to connect opposite poles.

2. What happens to the fields when two magnets are brought close together?

Interaction of fields. Unlike poles cause lines of filings to run from one magnet to the other. Like poles produce lines of filings that do not cross.

3. What is an equipotential line in a magnetic field?

It is a line joining points on successive field lines which have the same potential magnetic energy. These lines are perpendicular to the field lines identified by the filings.

4. How does the shape of a magnet influence the field pattern?

In a horseshoe magnet the two poles are close together, and the lines running from one pole to the other are also close together. The shape of the field depends on the shape of the magnet.

5. Is there any evidence that the field lines converge at a point within the magnet?

Yes, if the curve of each line were extended across the magnet, the lines would intersect at a point inside the magnet.

Conclusions and suggestions for further investigations:

A magnetic field extends out from the magnet in all three dimensions. Lines of force, as identified with the lines of filings, run from one pole to the other. Those lines running between unlike poles do not cross. Bringing unlike poles close together causes the lines to be concentrated into a small space. This should increase the force felt by an object placed in that field.

Further investigations: (1) If a flat bar magnet is turned on edge before the paper is placed on it, will the field pattern be similar? (2) Is it possible to cast a three-dimensional pattern using gelatin as a medium? (3) Are there "insulators" (shields) for magnetic fields?

Reporter ______________________ Date ______________________ 10 3 page 201

Team Members ____

Problem: What other techniques can be used to reveal information about magnetic fields?

Hypotheses:

A compass is a small magnet. Its needle should change position as the compass is moved around a magnet.

Attack: Trace the position of a bar magnet on a sheet of paper. Then move a small compass, starting at one end, and marking the position of the needle through a series of positions from one end of the magnet to the other. Draw a continuous line through the dots at each compass position. Repeat this procedure until you have created a network of lines around the magnet.

Materials:

bar magnet
small compass

Observations:

Students should submit a drawing as the major part of their observational record. The lines on it should be "heel to toe" markings that make complete lines running from one pole of the magnet to the other.

Questions:

1. Where is the pole of a magnet located as indicated by this experiment?

It is inside the magnet, rather than at the very end.

2. Is a magnetic field confined to a plane?

No, it is three-dimensional and reaches out in all directions around the magnet.

Conclusions and suggestions for further investigations:

This experiment reinforces the conclusions of Experiment 10–3.
Further investigation: Try to record the three-dimensional nature of magnetic fields.

10
4
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Reporter ______________________ Date ______________

Team Members ______________________________________

Problem: How will the motion of one magnet affect another magnet near it, but not touching it?

Hypotheses:

(1) It will do nothing to the other magnet.
(2) It will cause the other magnet to move.

Attack: Hang two magnets with the thread on the meter stick. The magnets should hang horizontally and yet be free to swing. When they come to rest, deliberately move one magnet in various ways to see what response occurs in the other one.

Materials:

2 bar magnets
meter stick
60-cm of thread

Observations:

As one magnet is deliberately moved, the other will move with it. If the first magnet is stopped after the second has started moving, the first magnet will start to move in unison with the second.

Questions:

1. Does this experiment contribute to your understanding of the force field around a magnet?

It helps to show that a magnetic field is felt at a distance. Direct contact between magnets is not necessary.

2. What would happen if you were to hang a dozen or more magnets in a row and then twist one at the end of the row?

If done very carefully, the oscillation introduced into the first one should be transmitted down the line of magnets.

Conclusions and suggestions for further investigations:

Energy of motion of a magnet can be transmitted to another magnet although they are not in contact. Magnets have effects at a distance.

Further investigation: Study the relationship between a pair of magnets and a radio transmitter and receiver.

Reporter ____________________ Date ____________________

Team Members ____________________

Problem: Is there any connection between magnetism and electric current?

Hypotheses:

(1) Electric currents are accompanied by magnetic fields.
(2) Electric currents are not accompanied by magnetic fields.

Attack: Connect a coil of wire to the dry cell. While the wire is connected explore around the coil with a small compass (or a magnet that is free to swing). Break the circuit and see what happens to the needle of the compass.

Materials:

coil of insulated no. 28 copper magnet wire, containing 200 or more turns
flashlight dry cell
small compass

Observations:

The orientation of the compass changes as it is moved in and around the coil of wire.

Questions:

1. Does it seem that an electric current is accompanied by a magnetic field?

Yes, the shifting orientation of the compass is strong evidence.

2. Could a magnetic field be used to produce an electric field and an electric current?

The answer to this question is a hypothesis. Students may get the idea that a moving magnet could induce a current in the wire.

3. Does it appear that there is a relationship between the direction of current flow and the polarity of the associated magnetic field?

Yes, when the current direction is switched, the compass reverses direction.

Conclusions and suggestions for further investigations:

Electric currents have magnetic fields associated with them.

Further investigation: Try to answer question 2, if a sensitive galvanometer (which measures electric currents) is available.

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Reporter ______________________ Date ______________

Team Members ______________________________________

Problem: Do fields, similar to magnetic fields, seem to exist around electrically charged objects?

Hypotheses:

If electrically charged objects attract or repel each other, they are surrounded by a force field similar to that of a magnet.

Attack: Rub the strips or loops of plastic with a piece of wool or fur. Observe the results. Bring other rubbed and unrubbed strips near the first strip. Rub a toy balloon and bring it near the rubbed strip.

Materials:

strips or loops from a plastic garment bag
piece of wool or fur
toy balloon

Observations:

Rubbing the plastic strips causes them to hang in an oval instead of straight down. Other strips are both attracted to it and repelled by it. The balloon is attracted by the strips.

Questions:

1. Does more than one kind of charge seem to exist?

Yes, if you assume that like charges repel and unlike attract. Direct observation shows the actual repulsion and attraction, but the charges, as the cause, must be hypothesized.

2. Does this experiment seem to indicate that all matter can become electrically charged?

This experiment strongly suggests such a possibility.

Conclusions and suggestions for further investigations:

The rubbing of materials such as plastics and balloons produces a condition that causes attraction in some cases and repulsion in others. It can be inferred that likes are repelled and unlikes are attracted.

Further investigation: Test more materials to see if the idea in question 2 is correct.

Reporter ______________________ Date ________________ 10 7 page 206

Team Members ______________________________________

Problem: What can a vacuum tube electroscope reveal about electric charges?

Hypotheses:

The electroscope allows the identification of a charge as positive or negative.

Attack: Connect the electroscope so that it is operational. Then bring various objects, charged and uncharged, near the antenna. Observe what happens to the lamp. Test the distance at which a charged object will affect the lamp when you wave the object around.

Materials:

vacuum tube electroscope
plastic strip
piece of wool or fur

Observations:

The charges on some objects cause the glow in the tube to disappear. The charge on other objects causes the glow to intensify. Some objects affect the tube when they are at a considerable distance from it, such as across the room.

Questions:

1. What kinds of materials collect and hold electric charges?

The materials used in this experiment (plastic strips, wool, fur) seem to hold electric charge. Such materials are called nonconductors.

2. From your experience with electric current and static charges, are you willing to accept the idea that all matter is electrical?

Yes, tentatively. It does appear that electric charges are associated with all kinds of matter.

3. Can electric fields act at different distances?

Yes, the fact that the charged objects did not touch the antenna of the electroscope indicates action at a distance.

4. We have now accepted the particle theory for matter. What does this experiment suggest about the nature of particles?

They are electrical in nature. They are capable of being charged either positively or negatively.

Conclusions and suggestions for further investigations:

Matter is electrical. Some objects acquire a positive charge when rubbed; others acquire a negative charge. Since the presence of a negatively charged object near the antenna drives electrons from the antenna onto the grid of the tube, the glow in the tube is extinguished. The presence of a positively charged object near the antenna pulls electrons from the grid onto the antenna and leaves the grid positive. This causes the tube to glow more brightly.

Further investigations: (1) Test other materials for charge. (2) Study charging by induction or conduction.

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Team Members ____

Problem: Can electric charge be isolated on a piece of conductive material?

Hypotheses:

(1) Conductive material can be charged if it is isolated so the charge cannot flow off.
(2) Conductive materials cannot be isolated enough to allow a charge to build up.

Attack: Suspend a square of aluminum foil by a thread. Bring it near a piece of charged plastic while your fingers are on the foil. Quickly release your hold on the foil and pull it away from the charged plastic. Then test the foil with the electroscope to see if it is charged.

Materials:

- 20-cm square of aluminum foil
- small strip of aluminum foil
- piece of plastic
- piece of wool or fur
- vacuum tube electroscope
- thread

Observations:

If done correctly, a charge can be isolated on the square of aluminum foil. It will then have an effect on the electroscope.

Questions:

1. How does the electric field around a charged object change with distance?

It decreases in intensity as the distance increases.

2. What is electrical induction? What relation does it have to the action of the vacuum tube electroscope?

Electrical induction is the process of charging an object without physical contact occurring. The movement of electrons between the antenna of the electroscope and the grid is induced by the approach of charged objects.

3. What properties can you assign to particles of matter as a result of studying Chapter 10?

Particles of matter are electrical and possibly magnetic. Some are conductors of electric charge and others are insulators.

Conclusions and suggestions for further investigations:

Conductors can be charged by induction. It is more difficult to isolate charges on conductors than it is on nonconductors.

Further investigation: Study the effect of the shape of the object on its tendency to hold a charge.

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Team Members ______________________________________

Problem: What kinds of changes are evident in a chemical reaction?

Hypotheses:

(1) New solids may appear.
(2) Color changes may occur.
(3) Gases may form and escape.
(4) Heat may cause a rise or a drop in temperature.

Attack: Put a nail in a copper sulfate solution and measure any temperature change. Note any other changes. Repeat the experiment with a piece of zinc.

Materials:

test tube
test tube rack
iron nail
copper sulfate solution
piece of zinc
thermometer

Observations:

Copper is deposited on both iron and zinc. The temperature rises in the zinc-copper sulfate combination. A gas (hydrogen) is released from the zinc.

Questions:

1. What changes indicate that a chemical reaction occurred when the iron nail was placed in copper sulfate solution?

A copper-colored deposit appeared on the nail.

2. Does this chemical reaction release heat or absorb it?

It releases heat.

3. What differences are apparent between the reaction of the iron and the zinc with copper sulfate solution?

The copper-colored coating may not adhere to the zinc very well. Bubbles of a gas may be quite evident on the zinc.

4. How could you set this reaction up to detect release of electrical energy?

This question is a primer for the next experiment and offers a chance for discussion in preparation for it. The basic requirement is to separate the zinc and copper and to analyze the experiment.

Conclusions and suggestions for further investigations:

In this experiment, the appearance of new solid substances and gaseous materials suggests that chemical changes are going on. Heat exchange is also observable, although with the small quantities involved, it takes careful observation to detect the changes in temperature that are evidence for heat exchange.

Further investigations: (1) Test many other combinations of solutions and solids to see if new materials are formed and if heat exchange occurs. (2) Pursue question 4 in an analytical way. This requires separation of zinc and copper so that the zinc reaction occurs at one location and the copper reaction at another. The two locations must be connected so that there is a complete circuit for any current to flow through, and a detector of the current or voltage must be present.

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Team Members ______________________________________

Problem: Is electrical energy released during chemical reaction?

Hypotheses:

(1) Electrical energy is associated with chemical reaction and is observable.
(2) Electrical energy has nothing to do with chemical reactions.

Attack: Two metals, each in contact with a solution of one of its compounds, can be connected by a solution bridge and by wires through a vacuum tube electroscope. Use such a system to attempt to observe electricity in relation to chemical reaction.

Materials:

- 2 250 ml beakers
- 1-by-10-cm strip of copper
- 1-by-10-cm strip of zinc
- 2 wires with alligator clips
- vacuum tube electroscope or voltmeter
- 200 ml of zinc nitrate solution
- 200 ml of copper sulfate solution
- 50 ml of ammonium nitrate solution
- rolled-up paper towel

Observations:

If both wires touch the tongue at once, the wires taste different before and after the paper towel bridge is installed between the beakers. (Note: Be sure to remind students that the taste test is not generally acceptable in the laboratory.) A voltmeter, if used, will show a small voltage (up to 1.0 volts) with the copper terminal positive.
Little charge will be observed with one cell and the vacuum tube electroscope. However, a half-dozen cells in series will produce a noticeable increase in the glow of the vacuum tube and/or in the meter reading. The best way to measure the voltage is with a sensitive voltmeter.

Questions:

1. What conditions must exist for current to be evident and for reaction to occur?

There must be a closed circuit connecting the beakers that contain the separated metals and solution. A current detection device must be part of the system.

2. Does either plate affect the vacuum tube electroscope?

The zinc and copper plates in a single cell will not have a noticeable effect on the electroscope.

3. How does this arrangement separate the parts used in Experiment 11–1?

The zinc and copper sulfate, which were together in Experiment 11–1, are now in separate beakers, but are connected by wires and a wet paper towel.

4. A chemical change modifies the condition of the substance involved. Relate this statement to the particle theory for matter.

Chemical change under the particle theory is change in the way the particles are associated with one another. In this experiment, this change in association involves a release of energy.

Conclusions and suggestions for further investigations:

Electrical energy is associated with chemical reaction. It is apparently one of the forms of energy that can come out of a reaction or be put into one.

Further investigations: (1) Study more metal and solution combinations. (2) Study dry cells and storage cells to see how they work.

Reporter ______________________ Date ______________ 11 3 page 222

Team Members ______________________________________

Problem: Do liquids conduct an electric current?

Hypotheses:

(1) All liquids conduct electric current.
(2) Some liquids conduct electric current.
(3) No liquids conduct electric current.

Attack: Set up a flashlight so that a complete circuit does not exist unless a current flows across a liquid. Test various liquids, solvents, and solutions for conductivity.

Materials:

- conductivity testing device complete with lamp and dry cells
- 10 250-ml beakers
- 100-ml quantities of alcohol, tap water, and distilled water
- 100-ml quantities of solutions of copper sulfate, zinc nitrate, ammonium nitrate, sodium chloride, sugar, and acetic acid (concentrated and dilute)

Observations:

The solutions of copper sulfate, zinc nitrate, ammonium nitrate, and sodium chloride all readily conduct current.

Tap water conducts slightly. The detector must be quite sensitive to detect it. With an extremely sensitive detector, it can be shown that distilled water has some capacity to conduct.

Sugar solutions do not conduct any better than the water used as a solvent for them.

Dilute acetic acid is a better conductor than concentrated acid.

Questions:

1. Why should both probes of the conductivity tester be made of the same metal?

If they were different, a voltage would be generated, as in the beaker in Experiment 11–2. If its polarity were opposite that of the dry cell, it might interfere with the conductivity test.

2. What seems to make a good electrolyte?

The metallic salts as a group seem to be good conductors. Solutions of acids might be good conductors, too, although this experiment tests only one.

3. Does the solvent have to be water for the solution to be an electrolyte?

The only solvent used in this experiment is water. Other solvents may produce just as good electrolytes.

4. What kind of particles exist in electrolytes compared to non-electrolytes?

Electrolytes must contain charged particles, since a current is produced by charges in motion.

Conclusions and suggestions for further investigations:

Conductivity seems to be a property of solutions rather than a property of all liquids. The solvent for making the solutions may need to be water. This experiment does not test other solvents.

Further investigations: (1) Test other solutions in water. (2) Test solutions in other solvents. (3) Test the effect of the amount of solute dissolved in a constant quantity of solvent.

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Team Members ____

Problem: Do some chemical reactions absorb heat as they take place?

Hypotheses:

Since some reactions already observed give off energy, it seems reasonable to expect that the reversal of these reactions absorbs energy.

Attack: A reaction that does not involve energy in an obvious way as it occurs is the reaction of Alka Seltzer in water. Study this reaction closely by dissolving a tablet in a measured amount of water and checking whether the water temperature changes during the reaction.

Materials:

beaker
mortar and pestle
thermometer
water
Alka-Seltzer tablets

Observations:

Dissolving (with associated release of gas) results in a reduction of temperature. As the Alka Seltzer tablet dissolves, the temperature of the water drops.

Questions:

1. What evidence for chemical reaction is apparent in this experiment?

A new material, the gas, appears.
The reaction is not readily reversible.

2. What change in temperature occurs? Why?

A slight cooling occurs. This might be the result of the change from solid to dissolved form, or it might be due to the formation of the gas.

3. How is the dry residue from the reaction different from the original tablet?

It doesn't react with water, although it does dissolve in water.

4. Can you relate this reaction to the particle motion theory?

The particles of Alka Seltzer react with water particles to produce new gas particles and solid particles that are dissolved in the water.

Conclusions and suggestions for further investigations:

This experiment provides further indication that energy is associated with the changes in particle organization that occur during chemical reactions. In this case, heat is apparently absorbed from the water as the particles change.

Further investigation: Study other reactions and solution formations that absorb energy. Try to trace absorption as a reaction goes one way and emission of energy as it goes the other way. Ammonium nitrate with ammonium chloride provides a striking example. As they dissolve, a distinct drop in temperature is evident. As they crystallize from saturated solutions, energy is liberated. One way to observe this energy is to place a drop of saturated solution on a warmed microscope slide and then observe it. As crystals form a crust on the drop, some interesting activity will be evident.

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Team Members ______________________

Problem: What factors affect the corrosion of metals?

Hypotheses:

(1) The presence of water may encourage the corrosion of metals.
(2) The corrosion of metals is unaffected by the presence of water.
(3) The presence of hydrogen sulfide encourages corrosion.

Attack: Place one ball of steel wool in one jar; one ball in another jar. Put one under moist conditions and the other under dry conditions. In the second pair of jars, place the pieces of silverware. In one of these jars introduce a means of producing hydrogen sulfide gas and in the other keep the air clean and dry.

Concentrated sulfuric acid is used as an absorber of moisture in the two dry jars. Dilute sulfuric acid reacts with iron sulfide to produce hydrogen sulfide gas in the moist jar containing silverware.

Materials:

4 quart-sized jars with lids
2 balls of steel wool
2 pieces of silverplated flatware
10 ml of concentrated sulfuric acid
5 g of ferrous sulfide
several pieces of string
50 ml of water

Observations:

The evidence for corrosion under all conditions may be slow to appear. The sulfide will produce dark areas on the silverware that will be like the tarnish usually associated with silverware.

As the steel wool in the moist jar rusts, the brown color will be very evident. Since a jar contains a limited amount of oxygen, opening the jar occasionally to let in a new supply of air will aid the rusting.

The dry jars will show very little if any corrosion.

Questions:

1. Is there any evidence of corrosion in the four jars?

In the moist atmospheres rust and tarnish are evident.

2. Have you ever smelled the gas produced in the ferrous sulfide jar before? Where?

The gas, hydrogen sulfide, smells like rotten eggs, and, in fact, is the source of the smell in a rotting egg.

3. Do these reactions seem to be spontaneous?

Yes, in the sense that they apparently occur at room temperature without addition of heat or ignition.

4. How can the particle motion theory be used to describe what happens in the jars?

The particles of the gases hydrogen sulfide and oxygen collide with the surface of the steel wool or the silverware. Some of them collide in such a way that they become bonded to the metal. In some way water seems to aid this reaction.

Conclusions and suggestions for further investigations:

Corrosion is more extensive in a moist atmosphere than in a dry one. Corrosion is evidently encouraged by the presence of both oxygen and hydrogen sulfide.

Further investigations: (1) Study the corroding effect of other gases. (2) Study the corrodibility of other metals.

Reporter ______________________ Date ______________________

Team Members ____

Problem: How is reaction rate affected by temperature?

Hypotheses:

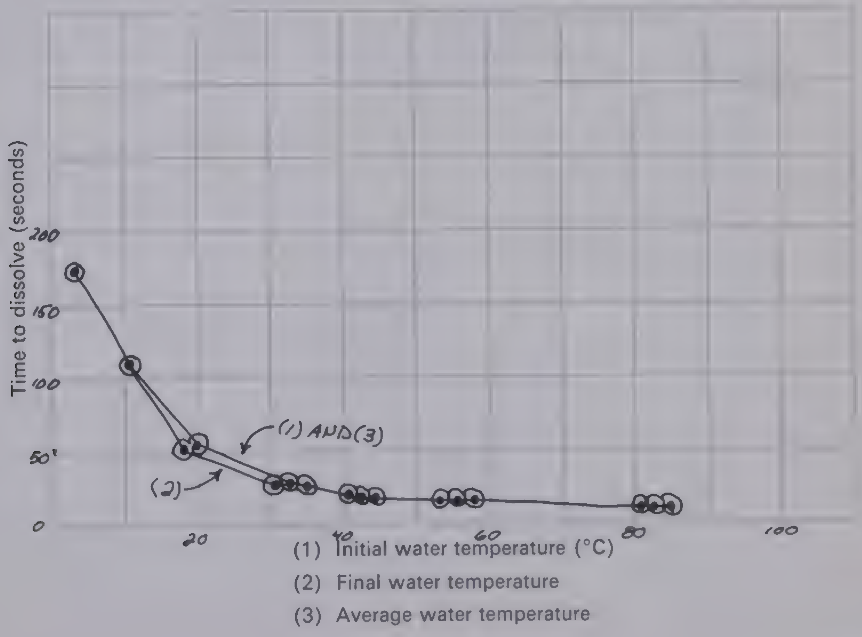
(1) Reactions occur faster at higher temperatures.
(2) Reactions occur faster at lower temperatures.
(3) Reaction rates are not affected by temperature.

Attack: Measure reaction rate for a particular reaction at many different temperatures. (Each team should use a different temperature.)

Materials:
250-ml beaker
thermometer
Alka-Seltzer tablet
100-ml quantities of water at a variety of temperatures

Observations:

Trial	1	2	3	4	5	6	7	8	9	10	Unit
Initial temp.	4	11	20	35	46	58	85				°C
Reaction time	180	110	60	30	25	20	13				sec
Final temp.	4	11	19	32	42	56	83				°C
Average reaction temp.	4	11	20	34	44	57	84				°C



Questions:

1. Does it make any difference whether the initial, final, or average temperature is used in plotting?

No, the general trend is evident in all three curves. In fact, in the graph shown, the three curves are practically indistinguishable.

2. What general statement about the effect of temperature on reaction rate can you make for this reaction?

As the temperature rises, the time necessary for the reaction decreases. The rate, or the fraction of the total reaction that occurs in one second, increases.

3. Does the amount of gas released seem to vary with the temperature?

There is less bubbling at the higher temperatures.

4. Predict what would happen if you dropped a second, third, and fourth Alka-Seltzer tablet into a beaker, or if you dropped in several tablets at once.

The presence of additional tablets would not change the reaction time appreciably.

Conclusions and suggestions for further investigations:

Higher temperatures cause this reaction to occur much more rapidly. It becomes almost explosive at temperatures above 50°C. At temperatures below 40°C, each 10°C rise seems to halve the reaction time, that is, double the reaction rate.

Further investigations: (1) Follow up the prediction of question 4. (2) See if other reactions show the same response to temperature change.

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Team Members ______________________________________

Problem: What effect does concentration have on reaction rate?

Attack: Choose a reaction in which the concentration of one of the ingredients can be varied quite readily while the other one is held constant. Carry out the reaction at a number of concentrations.

Hypotheses:

(1) Increased concentration will cause an increase in reaction rate.
(2) Increased concentration will cause a decrease in reaction rate.
(3) Concentration will not affect reaction rate.

Materials:

- 2 small test tubes (13 × 100 mm)
- 8 2-cm lengths of magnesium ribbon
- a dropper
- two thermometers
- test tube rack
- graduated cylinder
- dilute hydrochloric acid
- water

Observations:

Trial	1	2	3	4	5	6	7	8	9	10	
Concentration of acid	20	10	20	20	20						drops per 10 ml
Dissolving time	4.5	13	8	16	27*						~~sec~~ min
Acid Temperature	24	23	25	25	25						°C
Metal strips added											

* AT 27 MIN, A SUBSTANTIAL PORTION OF PIECE #4 WAS LEFT, BUT THE REACTION WAS VERY SLOW.

Students can attempt to graph data, but it is more important to emphasize that the number of acid particles that collide with the magnesium gradually diminishes and approaches zero.

Questions:

1. What effect does the concentration of the acid have upon the reaction rate?

The reaction is slower when the acid is less concentrated.

2. What happens to the reaction rate as successive pieces of metal are added?

The reaction is slower when more metal is added.

3. What change in temperature occurs? Does it seem to be related to rate of reaction and thus to concentration in this reaction?

There is a slight rise in temperature. The amount of the rise is greater for the faster reactions.

4. Can you use a particle motion theory to construct a mental picture of what happens in this reaction?

Particles of acid collide with particles of metal at the surface of the metal strip. The more acid particles present, the faster the reaction.

Conclusions and suggestions for further investigations:

The concentration of acid does affect the rate of reaction. The more acid in the solution, the faster the reaction. When more metal is added, the acid is used up and the reaction slows down.

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Team Members ____

Problem: What effect does surface area have on reaction rate?

Hypotheses:

(1) The greater the surface area, the faster the reaction.
(2) Surface area does not affect reaction rate.

Attack: Determine the time for a broken Alka-Seltzer tablet to react completely as compared with the reaction time for an unbroken tablet. Deliberately vary the amount of exposed surface.

Materials:

3 Alka-Seltzer tablets
mortar and pestle
250-ml beaker
water

Observations:

The whole tablet dissolves most slowly, the eight pieces go slightly faster, and the ground-up tablet goes very much faster.

Questions:

1. Can you relate this experiment to building a campfire or a fire in a fireplace?

Breaking wood into small pieces exposed much more area to the available oxygen. The reaction goes much faster.

2. We usually think of surface area in relation to solids. Do liquids and gases have a surface area (when considering chemical reactions)?

Yes, they do. They have a very extensive surface area consisting of the particle surfaces, rather than just an outside surface.

3. Is the surface area related to concentration as a factor affecting the rate of reaction?

Yes, the greater the concentration of a dissolved substance, the greater the total surface area of the particles of that substance.

4. How can the particle theory be used to explain the effect of surface area on reaction rate?

The particle theory allows us to describe reactions as contacts between particles. Thus, rate is determined by how rapidly particles can encounter each other.

Conclusions and suggestions for further investigations:

In a qualitative sense, this experiment indicates that surface area or opportunity for contact between materials is a critical factor in determining the rate at which materials can react.

Further investigation: Perform the experiment using magnesium ribbon both as a single strip and as a strip cut into many tiny pieces.

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Team Members ____

Problem: Will other substances than those that react influence the rate of reaction?

Hypotheses:

Experiment 11–5 may provide a clue to many students.

(1) Reaction rate is affected only by the nature of the reacting materials.

(2) The reaction rate is affected by the presence of other materials that are not affected by the actual reaction.

Attack: Compare the rate at which hydrogen peroxide decomposes when in the presence of various substances to its rate of decomposing with no substances present.

Materials:

6 test tubes
test tube rack
30 ml of 3% hydrogen peroxide solution
tiny quantities of manganese dioxide, copper metal, zinc metal, sodium chloride, calcium carbonate.

Observations:

Manganese dioxide causes decomposition. The other substances do not cause any change that is visible to the naked eye.

Questions:

1. Is there any noticeable reaction of hydrogen peroxide when a catalyst is not present?

No.

2. Why is the sixth test tube of hydrogen peroxide solution used as a control?

This tube shows how hydrogen peroxide solution by itself, without benefit of catalysts, decomposes.

3. Is the catalyst changed by the reaction? How can you answer this question without experimenting?

From this experiment, it is hard to tell. A careful effort to check before and after the experiment would be a necessary follow-up.

4. How can catalysts be described using the particle theory?

The presence of the catalyst modifies the particle so that they are susceptible to reaction.

Conclusions and suggestions for further investigations:

Only one of the substances, manganese dioxide, has a definite effect on the decomposition of hydrogen peroxide.

Further investigations: (1) Follow up question 3. (2) Try more substances as catalysts.

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Team Members ______________________________________

Problem: Can the equilibrium state of a chemical reaction be altered by adding energy?

Water shows no tendency to separate into its elements at room temperature. In its equilibrium state it is composed of nearly 100% water and almost no hydrogen or oxygen.

Hypotheses:

(1) Electrical energy will alter the equilibrium state of water.
(2) Electrical energy will not affect the equilibrium state of water.

Attack: Apply electric current to a solution of sulfuric acid and water to see if the solution is changed by the current.

Materials:

2 20-by-150-mm test tubes
250-ml beaker
2 electrodes
dilute sulfuric acid
water
source of direct electric current
wire and clips.

Observations:

As the current flows, gas bubbles form and escape at the electrodes in the two tubes. On one electrode the rate of bubble formation is much faster, and the bubbles are larger than those in the other tube.

Questions:

1. Why do you think the electrical energy causes this reaction to occur?

The electrical energy can affect the water particles and apparently cause them to separate.

2. How does the quantity of hydrogen gas compare with that of oxygen? Explain.

About twice as much hydrogen forms as oxygen. This suggests a two-to-one ratio of particles as a possible explanation.

3. Use the particle theory to describe this reaction.

The electrical energy separates water particles into particles of hydrogen and oxygen.

4. Why does sulfuric acid make the water a good conductor?

The acid increases the conductivity and allows the reaction to proceed much more rapidly.

Conclusions and suggestions for further investigations:

Electrical energy does alter the equilibrium state of water. It disturbs it to the extent that hydrogen and oxygen gases are produced.

Further investigations: (1) Measure carefully the quantities of gases produced. (2) See if other reactions can be treated in a similar manner.

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Problem: Can an equilibrium condition be produced in a chemical reaction by controlling the conditions of reaction?

Hypotheses:

If the products of the reaction can be trapped in the system, then equilibrium is possible.

Attack: Drop one Alka-Seltzer tablet in each bottle. Screw one cap on tightly and leave the other open.

Materials:

2 small cylindrical containers with caps
transparent adhesive tape
2 Alka-Seltzer tablets
timer
water

Observations:

The reaction in the open container goes to completion as the gas escapes. In the closed bottle, the gas production becomes less and less evident. Gas bubbles continue to appear, but much more slowly. The solid disappears. There is no convincing evidence that the chemical reaction which creates the gas is arrested by sealing the bottle. However, when the bottle cap is loosened, the escape of gas is sudden and very evident. Sealing again arrests the release of the gas.

Questions:

1. Can you control conditions to produce equilibrium in this experiment?

This experiment represents a good try. There is some doubt that it really produces an equilibrium between the chemical reactants. (See answer to question 2.)

2. Does this situation represent a single, simple equilibrium or is it complex?

Complex. Equilibrium is likely to exist between the dissolved gas and that out of solution, as well as between the original reactants (Alka Seltzer and water) and the products (carbon dioxide and solid).

3. When you loosen the cap and then tighten it on the closed bottle, what happens? Does this restore or disturb equilibrium?

It disturbs, then restores the apparent equilibrium.

4. Use the particle theory of matter to describe what happens to the equilibrium.

See discussion below.

Conclusions and suggestions for further investigations:

The reaction products can be kept in the reaction system, and the opportunity for equilibrium is created. Between gas and dissolved gas there is an equilibrium which is clearly affected when the cap is loosened and retightened. Whether an equilibrium exists in a chemical sense is debatable.

Further investigation: Check the effect that temperature would have on achieving equilibrium. For instance, see how the reaction would proceed at a temperature near or at 0°C.

Discussion for #4 above. Particles of Alka Seltzer and water collide and react. Gas particles and the other product collide and react also. As the amount of gas and second product build up in numbers of particles, the collisions among them increase. The rate of return to the original form also increases. One reaction slows in rate and the other increases in rate as equilibrium is approached. At equilibrium the rates are equal. By releasing some of the gas, one can upset the equilibrium. There is then less gas to react, and the reaction to form Alka Seltzer becomes slower than the reaction which forms the gas.

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Team Members ____

Problem: What conditions other than formation of a gas may prevent a reaction from reaching equilibrium?

Hypotheses:

Reactions produce products other than gases. If these remain in the system, equilibrium is possible. If they can be removed, equilibrium is prevented. If they are changed to something else, the equilibrium is upset.

Attack: Add a small amount of a sodium hydroxide solution to a copper nitrate solution. Note the formation of a solid substance. Add some ammonia solution.

Materials:

solutions of copper nitrate, sodium hydroxide, and ammonia
dropper for each solution
test tube

Observations:

Addition of the sodium hydroxide solution produces a bluish-white solid that floats in the blue copper nitrate solution. Addition of an appropriate amount of the hydroxide creates a condition in which the solid remains. Addition of the ammonia tends to reduce the amount of bluish-white solid and may remove it completely. The ammonia also produces a very deep blue color in the solution. The right amount of ammonia solution will produce the deep blue color but will allow some of the solid to remain.

Questions:

1. Do the reactions represent situations where equilibrium can exist?

Yes, the intent is to produce an equilibrium between the bluish-white solid and the deep blue substance produced when ammonia is added.

2. Without the presence of the ammonia the precipitate seems to remain the same in quantity. Why do you think it disappears partially or completely when ammonia is added?

It reacts with the ammonia.

3. Can you use the particle theory to describe the reactions you observed in this experiment?

The sodium hydroxide and copper nitrate particles react, producing the bluish-white solid. In turn, the particles of the solid can react with the ammonia particles. The reverse reactions are possible in all instances.

Conclusions and suggestions for further investigations:

When the deep blue color and the bluish-white solid exist together, an equilibrium exists. Production of the two forms is equal. If more of the ammonia is added, the solid disappears completely. This disappearance suggests that the concentration of one of the reacting substances can markedly affect the equilibrium.

Further investigation: Find other reactions where the equilibrium condition is very easily modified.

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Problem: What additional information about particle size and motion can be obtained from a study of osmosis?

Hypotheses:

(1) Osmosis is a process that lets both water and solute pass through membranes.
(2) Osmosis is a selective process that allows only water to pass through membranes.

Attack: Use carrots as membranes; hollow them out so they can be used as containers as well.

Materials:

3 medium-sized carrots
granulated sugar
3 beakers or flasks
spoon
water
glass slides (as covers)
toothpicks

Observations:

The carrot with the sugar in it filled with solution. The carrot standing in water did not seem to change. The carrot standing in a sugar solution lost the water that was in the depression.

Questions:

1. What do you think would happen if sugar solution were inside and outside the carrots but one solution was more concentrated than the other?

Water would move so as to equalize the concentration of sugar in the inside and outside solutions.

2. What conclusions can you draw about the size and motion of water molecules and sugar molecules?

We know from this experiment that water does move across the carrot membranes, but the sugar does not. This difference may be due to the small size of the water particles compared to the size of the sugar particles.

3. What factors other than size and motion might govern the movement of substances through a membrane?

Attractive or repelling forces acting on the particles might allow some particles to pass through a membrane and prevent others.

Conclusions and suggestions for further investigations:

Water passes through carrot membranes; sugar does not. The net result seems to be an effort to equalize inside and outside concentrations of the sugar solution.

Further investigation: Experiment with other substances that form solutions in water.

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Problem: Is the successive dilution of a solution helpful in determining particle size?

Hypotheses:

If particles are large, the dilution should produce blobs of color in the solution. If the particles are extremely small, the intensity of color will gradually diminish but will be uniform throughout the solution.

Attack: Put a single crystal of potassium permanganate into 50 ml of water. Split the amount in half. Save half and bring the other half up to the original volume. Split into halves again and bring half up to the original volume. Split into halves again and bring half up to the original volume. Follow this procedure looking for the existence of blobs or uniform color.

Materials:

- graduated cylinder
- several beakers
- crystal of potassium permanganate

Observations:

The color intensity gradually weakens but remains uniform throughout each dilution. It takes many dilutions to lighten the color to a point where it cannot be seen.

Questions:

1. What do you think you would see if you looked at the solution under a powerful microscope?

You might see nothing but a drop of liquid with a color tint to it, or you might see particles.

2. Relate your observations in this experiment to your observations in Experiments 6–4 and 7–3.

The motion of the milk and smoke particles helps to scatter them. The motion of the color particles contributes to the scattering of the color.

3. Do you now accept the particle theory and the particle motion theory as valid theories for matter?

Yes, they seem to be valid as a means of explaining many different observations.

Conclusions and suggestions for further investigations:

Their great capacity to scatter to produce uniform dilution in a large quantity of water suggests that the particles are extremely small and that the number of particles is very great.

Further investigation: Try to get additional information on the actual order of size of atoms and molecules. Good approximations can be obtained by spreading an oil drop on a water surface. A substance like oleic acid is best to use, since it has one end that is attracted to water and one end that is repelled.

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